# PETROLEUM REFINER

SPECIALIZED FOR THE OIL REFINING INDUSTRY, INCLUDING PETRO-CHEMICAL ENGINEERING, PETROLEUM SYNTHETICS AND NATURAL GASOLINE

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GRADY TRIPLETT
*Editor*


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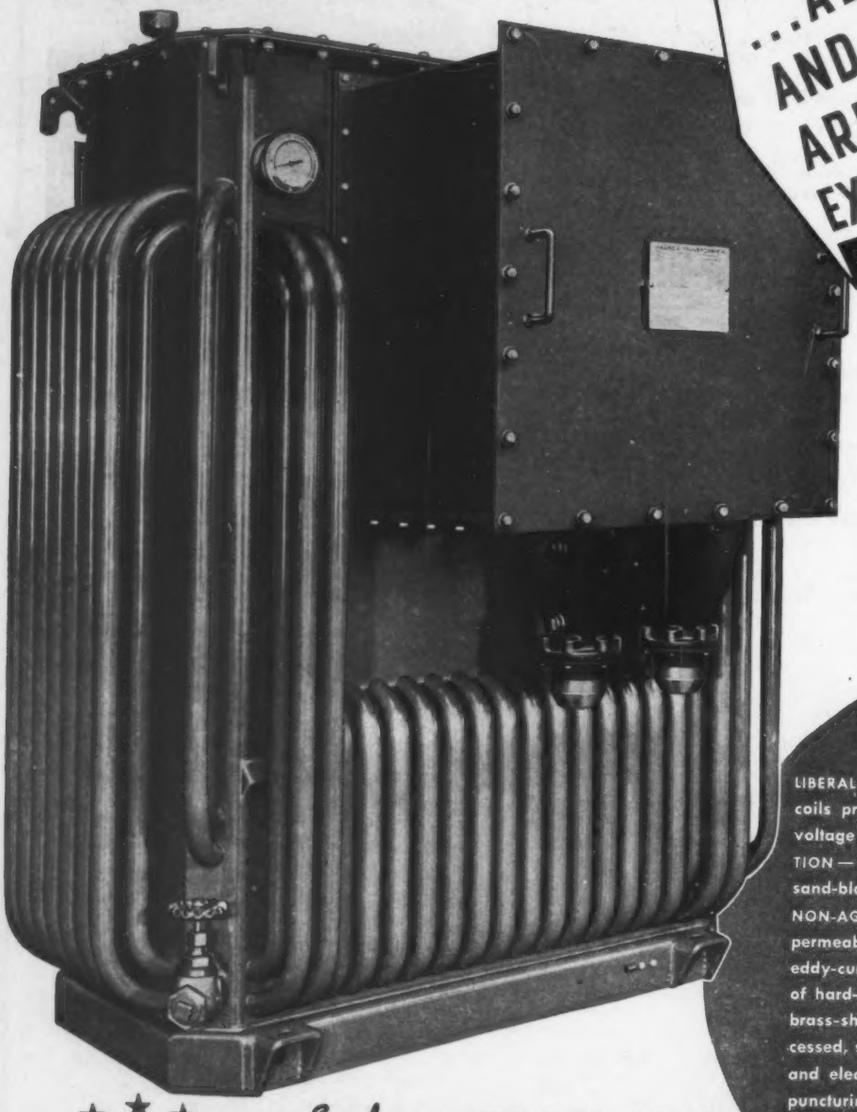

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VOLUME 21, NO. 11 NOVEMBER, 1942

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# THE LOOK BOX

ONE of the heartening notes of the Twenty-Third Annual Meeting of the American Petroleum Institute was the frequent reiteration of the soundness of the principle of free enterprise. This came from individuals in government as well as from individuals within the industry. Harold L. Ickes, Petroleum Coordinator for War, was outspoken in his allegiance to the desirability of clinging to competition. Ralph K. Davies, Deputy Coordinator, likewise gave it approval. The two as well as others went even further by expressing the hope that stimulation of the search for reserves of petroleum will not bring subsidy from the government.

***Also Worth Fighting For***

Concern over the issue of free enterprise came to the front because of the recent directive by which facilities of the petroleum industry have been pooled under direction of the government. Its justification comes from the necessities of prosecuting the war. The convictions within government that the directive is emergency in nature is hopeful.

No one can object to action which is taken as military assistance, unless the action fails of its objective. Since Directive 59 is not failing in its objective, the petroleum industry is correct in its determination to accept the order as beneficial to the war effort and for only the duration of the war.

It is advisable, however, not to dismiss the issue. Efforts within official Washington to socialize business have been too numerous in the past 10 years to justify the assumption that this has died in the war effort. It is more likely that it is dormant.

Men still believe that competition is extravagant and unnecessary. A conviction may be unsound and still prevail. Europe has systems contrary to the logic that supports free enterprise, still the systems prevail.

Free enterprise, another description of competition, offers the prospect of extravagance in that there is duplication of facilities, duplication of service, duplication of technical study. Extravagance fades whenever this competition results in better merchandise and better service at lower costs. Fortunately the petroleum industry can cite this result despite all its duplication of effort.

Monopoly is not efficient for the reason that it is not forced to improve either merchandise or service. It holds all the market regardless of what it produces or how it distributes its wares. Two refining plants do not exist where one seems sufficient. Two grades of gasoline are not offered where one is adequate.

Unfortunately the monopoly is blind. All too late it discovers competition across some boundary or across some ocean. The Axis nations are an example of monopolistic blindness. In neither Germany nor Japan was there immediate necessity for producing 100-octane aviation gasoline, to mention just one instance. Competition existed but not at home. Consequently the efficiency of monopoly faces the disaster of the extravagance of competition.

A monopoly of government is less efficient than a commercial monopoly. When under complete domination by the state, a monopoly does not face the necessity of making a profit. What it does

becomes routine and it lags from technology to service.

Its own accomplishments plus the examples of blindness in Axis economy are on the side of the petroleum industry as it maintains its claim of the right to duplicate facilities and technology while it discards equipment and makes progress. The petroleum industry will be within its rights as well as within its duties to the nation if it safeguards the principle of free enterprise.

THIS insight into the extension of chemical processing into petroleum refining is from the October issue of "Industrial Bulletin," published by Arthur D. Little, Inc., the chemical engineering organization of Cambridge, Massachusetts. Under the title of "A New Industry" synthetic rubber is analyzed in light of immediate necessity. What it may mean for the future and for advancement in processing is thus analyzed:

### Along With Rubber

"By-products, largely lower hydrocarbons such as propylene, of the butadiene production are comparable in quantity produced to the butadiene itself and are available at the plant for further synthesis. Depending upon the extent to which synthetic rubber is displaced after the war by natural rubber, there will be available a reservoir of hydrocarbon raw material to be shifted from rubber synthesis to synthesis of other products. There will be a large reservoir of experience in the design and operation of facilities for the production of such hydrocarbon raw materials. Adequate supplies of the basic petroleum seem assured for almost any size of program, when it is realized that the weight of Buna S called for by the program will represent less than one-half percent of the weight of the 1941 production of crude oil.

"Superimposed on the war material program for synthetic rubber and carried by the petroleum industry alone is the aviation gasoline program. Aviation gasoline is made partly by cracking, thermal and catalytic, of petroleum and partly by synthesis of special hydrocarbons and mixtures. The bulk of aviation gasoline, or even of its synthetic components, dwarfs the Buna S program. This will be another reservoir of material and experience for later utilization by chemical industry.

"There is another side to the synthetic rubber picture, in that plasticizers, stabilizers, extenders, tackifiers, and other compounding ingredients must be provided to make the synthetic workable and useful. In the development and manufacture of suitable materials for these requirements many small companies, as well as the few large ones, have been engaged. Ideal materials have not been produced, but the search goes on, for it is realized that manufacture of these auxiliary materials can be an important source of revenue.

"The position of synthetic rubber in the post-war recovery is a subject for speculation. Taking only into account the huge governmental investment in the synthetic program and the comparative production costs when the synthetic product is based upon petroleum, it would seem entirely possible that the natural product will occupy a very secondary position. So much will happen before the post-war period arrives, however, that no conclusion on this subject can be reached now."

THIS insight into the extension of chemical of the safety engineer. Circumstances beyond his control compel that he strive for fewer accidents while hazards are increased through necessity.

### Tact and Ingenuity

Conditions within the equipment industry are such that no plant can have what good operating practice dictates. Ordinary steel must be used where alloys would be preferable. Equipment must be kept in use beyond its normal expectance.

For a long time the safety director has contended that accidents are in large part due to human error rather than failure of equipment. In this approach he has been successful because his premise was sound. In turn the workman came to look upon accidents as something to prevent by sensible working methods. No longer can the human being be held responsible for his former share of mishaps. When equipment is not what the design engineer or the safety engineer prefers, failures will be more numerous.

It will require tact to bring workmen to realize that another attitude is essential to the safest working conditions.

Ingenuity is the answer to devising methods of bringing safe conditions about under this necessity of working with equipment, all of which is not of the preferred class.

PERHAPS it should be brought to the attention of the investigating committees, whose theme seems to be that the petroleum industry is rushing in where others should be left alone. At any rate

### Drums and Cans

drums and cans, denied as shipping containers because of the metal shortage, now are being made of other materials and in neither instance did the industry use any of its own products. All this, despite some interest in plastics.

Plywood is the material for the drums, with a bit of metal to aid in handling. For cans the industry has turned to paper as the base and plastics from farm products to make containers liquid proof.

# API Hydrocarbon Research

## A Four-Year Summary of Hydrocarbon Research

CECIL E. BOORD, Supervisor, API Hydrocarbon Research Project,
The Ohio State University

**THE American Petroleum Institute Hydrocarbon Research Project completed its initial 4-year period on August 31, 1942. Eighty-four hydrocarbons and other compounds have been prepared in quantities sufficient for engine test under six sets of conditions. The total quantity of product prepared is approximately 106 gal; 38 of these hydrocarbons have been purified by recrystallization to a purity of 99.9, and 326 samples of the high-purity products have been distributed to other workers for physical tests. The program is supported by 25 petroleum refiners, development laboratories, manufacturers of refinery equipment, and automobile manufacturers. The project has been authorized for a fifth year.**

**This paper was presented to the Division of Refining, before the twenty-third annual meeting of the American Petroleum Institute, Chicago, November 10, 1942.**

THE American Petroleum Institute Hydrocarbon Research Project was begun September 1, 1938, under the sponsorship of 25 industrial firms including petroleum refiners, development laboratories, automobile manufacturers, and manufacturers of refinery equipment. The program was designed to operate for an initial period of four years, and a fifth year of operation has been authorized.

The program is divided into three parts:

1. The synthesis and purification of hydrocarbons in the gasoline range.
2. The testing of these hydrocarbons under six sets of engine conditions. Later the testing of a number of hydrocarbons on a supercharged engine was added.
3. The measurement of physical and thermal constants on highly refined samples of each hydrocarbon.

The synthesis and purification of the hydrocarbons are carried on at The Ohio State University. A list of from 85 to 100 hydrocarbons was selected to include typical examples of the paraffin, olefin, diolefin, acetylene, aromatic, cycloparaffin, and cycloolefin series. The preliminary survey was limited largely to the eight carbon-atom level. From 1 to 1¼ gallons of hydrocarbons of 96 to 99 percent purity are prepared for the engine tests. A "best liter" of each product is reserved for further purification and preparation of the product to be used in thermal- and physical-constants work.

The engine-test program is carried out under six sets of engine conditions by the General Motors Research Laboratory, under the supervision of Wheeler G. Lovell. The supercharged-engine tests are made by the Research Laboratories of the Ethyl Corporation under the supervision of Samuel Heron.

A large number of hydrocarbons have been purified to a purity of 99.9 percent, and are distributed to a select group of physical chemists and physicists for physical and thermal measurements. The distribution of these products is under the supervision of George Calingaert of the Ethyl Corporation.

The fourth year of operation closed August 31, 1942. Eighty-four hydrocarbons or other products have been prepared or certified for engine test. Twenty-seven paraffins, 12 olefins, 2 diolefins, 2 acetylenes, 20 cycloparaffins, 3 cycloolefins, 8 aromatics, 5 bicyclohydrocarbons and terpenes, and 5 other compounds are included in the list. The total product prepared, including "best-liter" material, equals 404.5 liters, or 106 gallons. Thirty-eight hydrocarbons have been prepared in high purity, and 326 samples distributed to other workers for physical tests.

Thirty men have received a part or all of their graduate chemical training while serving as part-time assistants on the staff of the laboratory at The Ohio State University. Twelve of these have received, or will receive, the Ph.D. degree.

The contributing firms and their representatives are:

*D. P. Barnard, Standard Oil Company (Indiana); E. G. Borden, Cities Service Oil Company; R. E. Burk, The Standard Oil Company (Ohio); *George Calingaert, Ethyl Corporation; Don E. Carr, Union Oil Company of California; David E. Day, Richfield Oil Corporation; *Gustav Egloff, Universal Oil Products Company; S. W. Ferris, The Atlantic Refining Company; *R. A. Halloran, Standard Oil Company of California; J. Bennett Hill, Sun Oil Company; W. E. Kuhn, The Texas Company; *W. G. Lovell, Research Laboratories Division, General Motors Corporation; and R. E. Luton, The Ohio Oil Company.

Also E. J. Mary, The Globe Oil and Refining Company; J. T. McCoy, Tide Water Associated Oil Company; A. E. Miller, Sinclair Refining Company; C. W. Montgomery, Gulf Research and Development Company; *E. V. Murphree, Standard Oil Development Company; Roger Newton, Catalytic Development Company; G. G. Oberfell, Phillips Petroleum Company; J. W. Poole, Lion Oil Refining Company; J. B. Rather, Socony-Vacuum Oil Company, Inc.; W. B. Ross, The Pure Oil Company; L. C. Rubin, The M. W. Kellogg Company; and S. Tijmstra, Shell Development Company.

The representatives of the contributing firms form the Sponsors' Committee. The persons whose names are asterisked are also members of the Advisory Committee. D. P. Barnard is chairman of both committees.

On behalf of the staff of the laboratory at The Ohio State University, the supervisor wishes to take this opportunity to thank the sponsors for their support and fine spirit of cooperation.

# The Physical Constants of Some Hydrocarbons in the Gasoline Boiling Range

CECIL E. BOORD, Supervisor, API Hydrocarbon Research Project,
The Ohio State University

**THE paraffin hydrocarbons are best regarded as a collection of many subseries, each containing a characteristic structural group. These subseries become more numerous and more complex as the number of carbon atoms is increased. The normal paraffins form the most complete and the simplest structural type. As the possible structures for the paraffins are developed, other uniform structural types will emerge, i. e.:**

| $n\text{-}C_nH_{2n+2}$ | $n\text{-}C_nMe_{2n+2}$ |
|---|---|
| *n*paraffins | *n*methylparaffins |

**There is some evidence that melting point is a function of the purity of the structural type. Carbon atoms 2 and 3 in a paraffin chain are key positions from the standpoint of physical-constant modification. Additional methyl groups substituted in the 2-position augment the effect of the methyl group at the end of the chain. Additional methyl groups substituted in the 3-position tend to counterbalance the effect of the methyl group at the end of the chain.**

**Double bonds when introduced into a hydrocarbon structure act in a similar manner. Their effects may be additive or counterbalanced. The effect of point of unsatuartion may be counterpoised or added to that of a methyl group. Numerous graphs and tables are used to illustrate these points.**

HYDROCARBONS are divided into two great groups, cyclic and non-cyclic in structure. The paraffins form the basis of the non-cyclic group, inasmuch as the monoolefins, diolefins, and acetylenes may be regarded as derivatives of the parent saturated hydrocarbons having the same arrangement of carbon atoms.

In like manner the cycloparaffins form the structural basis of the cyclic group. Cycloolefins, diolefins, and triolefins may be regarded as derivatives of the cycloparaffin having the same carbon skeleton. The aromatic series form a particular case among the cyclotriolefins in which the three double bonds are spaced symmetrically around a six-atom carbon ring.

It is customary to think, and to speak, of the paraffins as a single series. Those who have worked intimately with these compounds know such a concept does not express the whole truth. The normal paraffins form a more logical series, whereas the 2-methylalkanes, 3-methylalkanes, 2,2-dimethylalkanes, and 3,3-dimethylalkanes each form analogous series having a characteristic structural group. The paraffins, therefore, are to be regarded as a collection of many subseries, the collection growing more numerous and the structure more complex as the number of carbon atoms is increased.

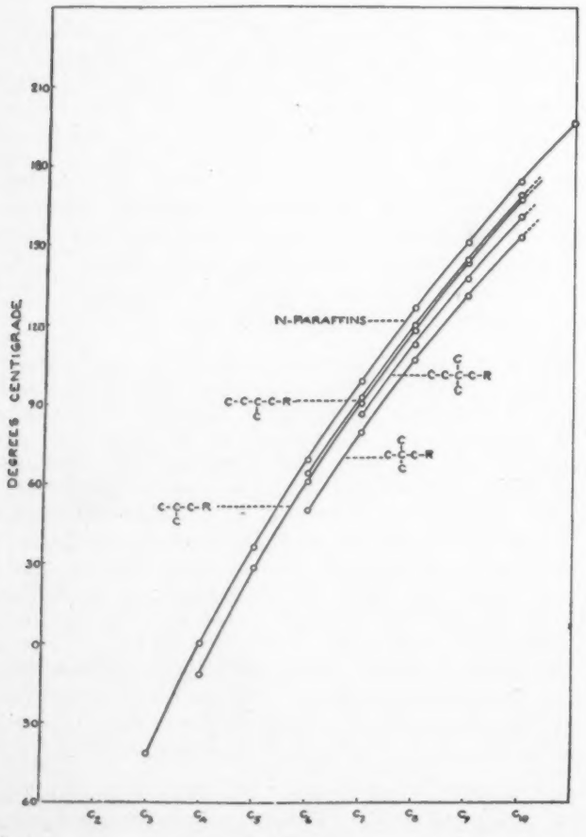



**FIGURE 1**
**Paraffin Boiling Points.**

When the boiling points, densities, or refractive indices of the paraffins are plotted against carbon content, a compact family of curves may be drawn, each representing a characteristic structural isomer.

Many attempts have been made to evolve formulas which will reproduce and extend these curves.[1] Formulas of this type may be quite accurate and can be very useful, but are likely to deviate from the observed values for those curves which lead far down into the low molecular weights. Such formulas are empirical, and do not give even the faintest clue as to why all branched paraffins boil lower than the normal isomer, or why those isomeric paraffins with methyl groups in the 2 and/or 2′ position are less dense and less refractive than the normal isomer whereas those isomers bearing methyl groups in the

3 and/or higher positions are more dense and more refractive.

It has long been known that the melting points of the normal paraffins do not fall on a smooth curve.[2] When the melting points are connected in numerical

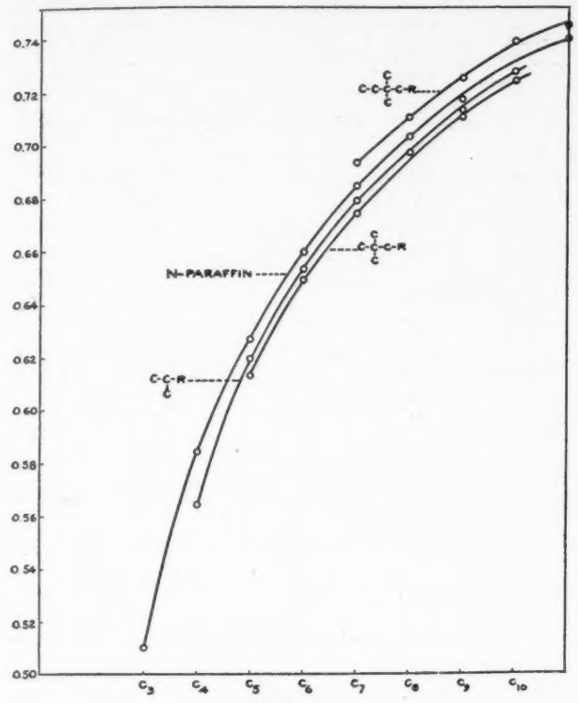



**FIGURE 2**
**Paraffin Densities, $d_4^{20}$.**

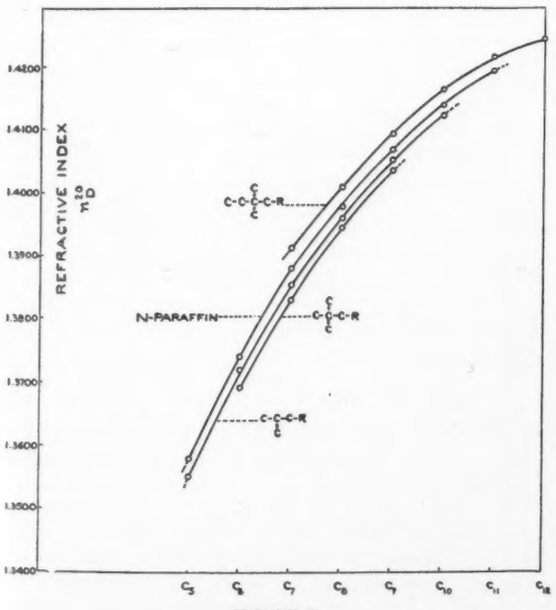



**FIGURE 3**
**Paraffin Refractive Indices.**

sequence, an alternately large and small rise in the melting point becomes obvious. Two smooth curves can be drawn, one connecting those members of the series containing an even number of carbon atoms, and the other connecting those with an odd number of carbon atoms.

A similar alternation has been observed for the melting points of the $\alpha,\alpha'$-dicarboxylic acids.

The alternation in the melting points is attributed commonly to the polarity of the terminal groups at the ends of the chain. When the number of carbon atoms is odd, these terminal groups reinforce each other; and when the number is even, their effects are opposed.

The boiling points of the *n*paraffins, as we have seen, do fall on a smooth curve. The alternation has disappeared, but the effect may be made apparent if one considers the rise in boiling point produced by replacing each hydrogen atom of a parent paraffin in turn by a methyl group. Let us consider, for example, *n*heptane. If we substitute a methyl group for hydrogen successively upon carbon atoms 1, 2, 3, and 4, the 4 isomers *n*octane, 2-methylheptane, 3-methylheptane, and 4-methylheptane will be produced. The boiling-point increases produced by these substitutions

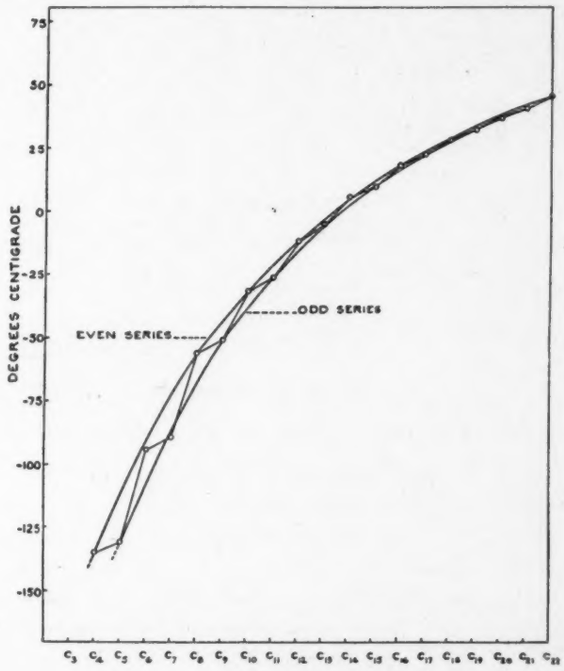



**FIGURE 4**
**Paraffin Melting Points.**

form an alternating series. In Figure 5 the above procedure has been applied to each of the 9 isomeric heptanes in turn. In general, the alternation is apparent in each case. The substitution of methyl groups on carbon atom **2** greatly enhances the effect and results in an abnormally low rise in the boiling point.

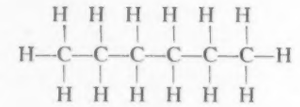
The introduction of a methyl group upon carbon atom **3** counterbalances the effect of the methyl group in position **1**. The increase in the boiling point from *n*heptane to *n*octane is 27.2° C.; but when one considers all the substitutions by which a heptane can be converted to an octane, the boiling-point rise may be as low as 17.7° C. or as great as 35.8° C.

The result of this alternating effect of the methyl group is to cause an overlapping and confusion in the initial stages of the boiling-point curves. In Figure 6 the heptane-octane segment of the boiling-point curves has been magnified, and the actual differences accentuated by moving the octane scale back 25° C.

It is immediately apparent the curves for the

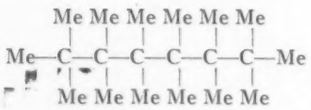
2-methyl-, 3-methyl-, 2,2-dimethyl-, 2,4-dimethyl-, and the 2,2,4-trimethyl derivatives are quite similar to the curves of the normal hydrocarbons. Actually, the slope is a little greater in each case. Contrasting sharply with these, the curves for the 2,3-dimethyl-, 3,3-dimethyl-, and 3-ethyl- derivatives form a group very similar in character but having a slope less than that of the normal hydrocarbon.

These variations in the physical constants, caused by moving a methyl group from position to position on a parent hydrocarbon, remind us our concept of the paraffin series is always derived from a single point of view. Invariably we think of paraffins only as hydrocarbons. Each isomer is derived by substituting methyl groups for the hydrogen on the normal paraffin corresponding to the longest chain. Seldom do we carry the development of this concept to its logical conclusion, when all of the hydrogen atoms of the parent have been replaced by methyl groups. The normal paraffins form a series, each member of which is composed of a continuous chain of carbon atoms fully saturated by hydrogen atoms as illustrated by "A." An equally logical series may be conceived, each member of which is composed of a continuous chain of carbon atoms fully saturated with methyl groups as illustrated by "B."



$C_nH_{2n+2}$

"A"



$C_n(CH_3)_{2n+2}$

"B"

The methyl carbon series, beginning with neopentane and continuing through hexamethylethane and to higher members, as indicated by "B," forms an equally logical and equally systematic series as the normal paraffins. Between these two systematic structural series types lie most of the isomeric paraffins with which we are familiar.

When we took up the purification of the 18 isomeric octanes in our laboratory, we found *n*octane and the 3 methylheptanes to crystallize readily and to give sharp melting points. At the other extreme, tetramethylbutane and the four trimethylpentanes also crystallized with greater or less ease. Thus far ethylhexane and the six dimethylhexanes have resisted all efforts to obtain them consistently in the crystalline condition. One may well ask why do these mixed structural types tend to resist crystallization.

Or again, it is interesting to recall that our reform-

**TABLE 1**

***n*Octenes and *n*Octynes**

| Hydrocarbon | Melting Point (°C) | Boiling Point (°C) | $d_4^{20}$ | $n_D^{20}$ |
|---|---|---|---|---|
| 1-Octene | —102.1 | 121.6 | 0.7150 | 1.4090 |
| 2-Octene | — 94.0 | 125.2 | 0.7192 | 1.4130 |
| 3-Octene | —110.0 | 123.2 | 0.7146 | 1.4128 |
| 4-Octene | — 93.8 | 122.3 | 0.7136 | 1.4119 |
| 1-Octyne | — 79.5 | 126.2 | 0.7457 | 1.4159 |
| 2-Octyne | — 62.0 | 137.1 | 0.7591 | 1.4269 |
| 3-Octyne | —105.0 | 132.9 | 0.7529 | 1.4250 |
| 4-Octyne | —102.9 | 131.5 | 0.7506 | 1.4247 |

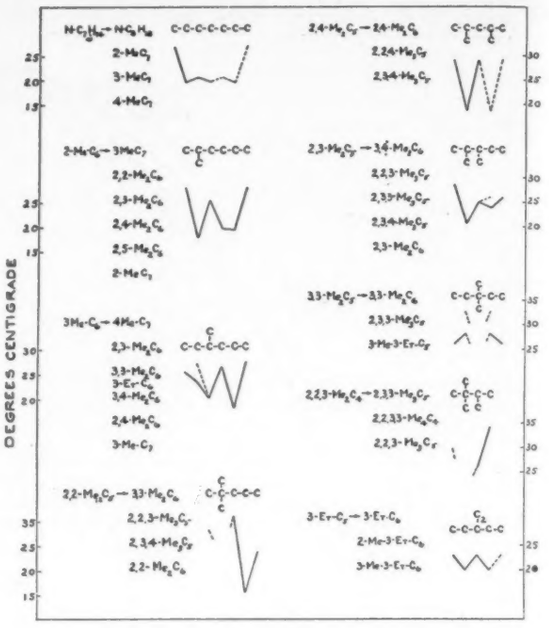



**FIGURE 5**
**Heptane-Octane Boiling-Point Rise.**

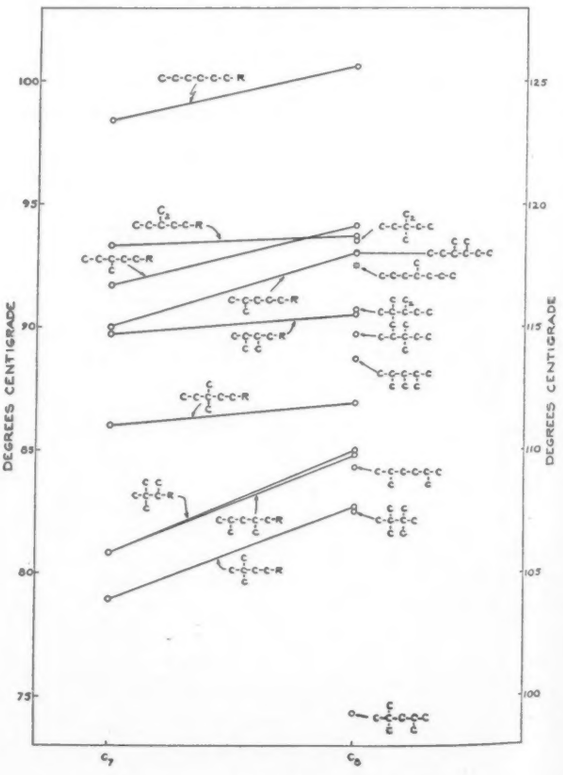
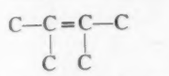
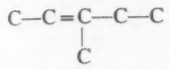
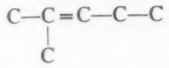
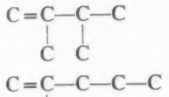
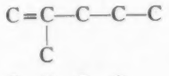
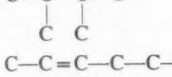
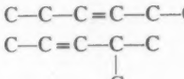
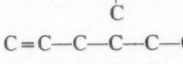
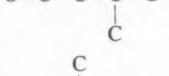
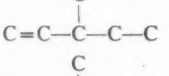
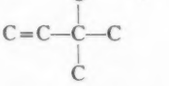
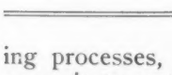
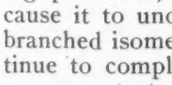



**FIGURE 6**
**Heptane-Octane Boiling Points.**

**TABLE 2**

**Hexenes and Hexanes**

| Hexene Structure | Olefin Type | Boiling Point of Hexene (°C) | Boiling Point of Hexane (°C) | Deviation for Olefin (°C) |
|---|---|---|---|---|
|  | V | 73 | 58.1 | +14.9 |
|  | IV | 69.9-70.2<br>65.1-65.7 | 63.2 | + 6.9<br>+ 2.2 |
|  | IV | 67.2-67.5 | 60.2 | + 7.2 |
|  | III | 66.2-66.7 | 63.2 | + 3.3 |
|  | III | 61.5-62.0 | 60.2 | + 1.6 |
|  | III | 56.0-56.5 | 58.1 | — 1.8 |
|  | II | 67.0-68.1 | 68.1 | — 0.7 |
|  | II | 66.6-66.9 | 68.7 | — 1.9 |
|  | II | 57.7-57.8<br>54.2-55.2 | 60.2 | — 2.4<br>— 5.5 |
|  | I | 63.4-63.7 | 68.1 | — 5.1 |
|  | I | 53.6-53.9 | 60.2 | — 6.4 |
|  | I | 53.6-54.0 | 63.2 | — 9.4 |
|  | I | 41.2 | 49.7 | — 8.5 |

ing processes, when applied to a normal paraffin, cause it to undergo isomerization to a more highly branched isomer but the isomerization does not continue to complete methylation. On the other hand, one may start with a highly methylated product and by the same reforming process lengthen the chain approaching the intermediate isomer from the opposite side. It would be interesting to know the motivating forces which cause these systematic structural types to become merged in an intermediate hybrid structure.

When a point of unsaturation is introduced into a paraffin producing an olefin or an acetylene, quite analogous effects are produced. Each isomeric paraffin becomes the parent of a group of isomers. The resulting change in the value of the physical constant is a function not only of the structure of the original paraffin, but also of the position in which the double bond is introduced. Table 1 shows the melting points, boiling points, densities, and refractive indices of the *n*octenes and *n*octynes.

It will be observed that the melting points are alternately lower and higher as the point of unsaturation passes from position **1** to **2** to **3** to **4**. The boiling points, densities, and refractive indices are lower for position **1**, higher for position **2**, and then fall as the point of unsaturation passes on toward the middle of the chain.

The character of the regularities between the physical constants and structure when applied to all the isomers of a given family are well illustrated by the boiling-point relationships between the hexenes and hexanes.

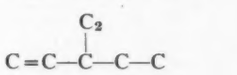
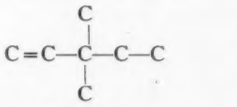
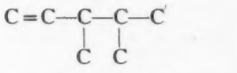
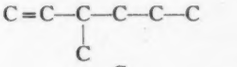
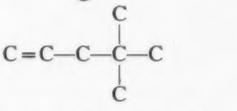
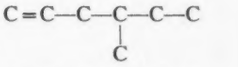
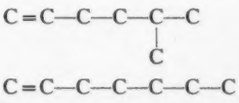
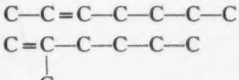
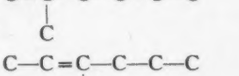
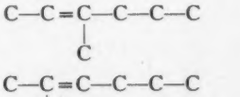
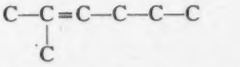
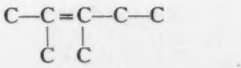
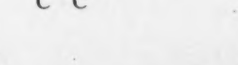
The difference between the boiling points of the hexenes and the corresponding hexane are shown in the last column of Table 2. The change in boiling point caused by converting tetramethylethane to tetramethylethylene, an olefin of type V, is large and positive—this difference of the olefin finally reaching large negative values for the hexenes of type I. The four butylethylenes obey the usual boiling-point rule *"the more highly branched the alkyl group, the lower the boiling point."* Not only is this true; but, in general, the lower the boiling point, the greater the lowering caused by the introduction of the double bond.

The hexenes of types IV and V at the top of the table show the effect of an accumulation of methyl groups around a double bond. This effect was first pointed out by Pawlow,[3] who called attention to the fact that *"an olefin may be branched in such a way as to cause an increase in its boiling point."*

These regularities are still more obvious when one studies the difference produced by introducing a point of saturation into the isomeric heptanes. Table 3 shows the differences in the boiling points, densities, and refractive indices first for the heptenes of

**TABLE 3**

**Heptenes Vs. Heptanes**

| Heptene Structure | Deviation in: Boiling Point (°C) | $d_4^{20}$ | $n_D^{20}$ |
|---|---|---|---|
|  | —10.0 | +0.0014 | +0.0061 |
|  | — 9.1 | +0.0024 | +0.0080 |
|  | — 9.3 | +0.0054 | +0.0069 |
|  | — 7.7 | +0.0078 | +0.0083 |
|  | — 7.5 | +0.0079 | +0.0093 |
|  | — 5.3 | +0.0099 | +0.0098 |
|  | — 4.2 | +0.0147 | +0.0103 |
|  | — 4.65 | +0.0157 | +0.0121 |
|  | — 0.15 | +0.0197 | +0.0164 |
|  | + 1.3 | +0.0211 | +0.0189 |
|  | + 1.4 | +0.0262 | +0.0193 |
|  | + 4.5 | +0.0300 | +0.0224 |
|  | + 8.0 | +0.0310 | +0.0291 |

type I, and second for those heptenes having a gradual accumulation of methyl groups about the double bond.

The boiling points of the olefins of type I are lower than those of the corresponding saturated hydrocarbons. The difference is large when the point of unsaturation lies close to the point of branching, and becomes progressively smaller as the point of branching recedes down the chain. The densities and refractive indices of the olefins are in all cases greater than those of the corresponding paraffin, the difference being small when the boiling-point difference is large and negative. As the negative boiling-point difference becomes less, the changes in density and refractive index become progressively greater, the alternation in the three physical constants being regular and roughly parallel. As methyl groups accumulate around the double bond, the boiling points of the olefins become greater than those of the parent paraffins—the differences increasing with the number of methyl groups. Simultaneously, the differences for the density and refractive indices continue to increase, reaching a maximum in the most highly methylated derivative, trimethylethylethylene.

In an earlier paper[4] we sought to coordinate the physical constants and structure of the simple paraffins, olefins, and diolefins. The present paper strengthens and extends the views there expressed. The **2** and **3** positions of a paraffin chain are key positions from the standpoint of physical-constant modification.

The effects of structure on physical constants may be summarized as follows:

*Boiling points:* Branching in a paraffin hydrocarbon always lowers the boiling point below that of the corresponding normal isomer. A methyl group in position **2** lowers the boiling point several degrees, and 2 such methyl groups lower it still further—the total sometimes being more than double that produced by the first methyl group. The methyl group in position **3** is apparently counterbalanced by the methyl group at the end of the chain (position **1**). The lowering, therefore, is not so great as that produced by substitution in position **2**. Two methyl groups in position **3** give a still greater lowering.

When a point of unsaturation is introduced into the paraffin structure in the $\alpha$-position (**1-2**), the boiling point also is lowered by several degrees. The double bond in the $\beta$-position (**2-3**), however, lowers the boiling point only slightly—the effect again apparently being counterbalanced by the methyl group at the end of the chain. When these two structural modifications are simultaneously present with the double bond in the (**1-2**) position and an accumulation of methyl groups on carbon atom **3**, the effects are additive, producing a maximum lowering in the boiling point.

*Density and refractive index:* It has been shown[5] repeatedly that methyl groups in position **2** tend to lower both density and refractive index. An accumulation of two methyl groups in this position is still more effective. A methyl group in position **3**, however, sharply increases both the density and the refractivity, and two methyl groups are more effective than one.

In general, all unsaturated compounds are more dense and more refractive than the parent saturated hydrocarbon. When the point of unsaturation is in the $\alpha$-position, and there is an accumulation of methyl groups on carbon atom **3**, the 2 factors neutralize each other—with the result there is a minimum change in density and refractivity. When the double bond is surrounded by methyl groups, as in olefins of types III, IV, and V (see Tables 2 and 3), the net result is an increase in all 3 of the physical constants by the maximum amount. The effect produced is as though the methyl groups surrounding the point of unsaturation serve to multiply the effect of a double bond in the $\beta$-position.

Double bonds in the conjugate position give strong increases to all three of the physical constants. Two methyl groups in the conjugate position (on adjacent carbon atoms) greatly increase the density and refractive index, although the branching still lowers the boiling point.

As the characteristic structural group of a paraffin or olefin becomes more complex, a larger number of carbon atoms is involved. Once the characteristic structure is completed, continued lengthening of the chain develops the physical-constant curve in a perfectly normal manner.

## References


[1] *a*, Egloff, Sherman, and Dull, *J. Phys. Chem.* **44,** 730 (1940).
*b*, Deanesly and Carleton, *J. Phys. Chem.* **45,** 1104 (1941).
*c*, Francis, *Ind. Eng. Chem.* **33,** 554 (1941).
*d*, Collingaert and Hladky, *J. Am. Chem. Soc.* **58** 153 (1936).
*e*, Kurtz and Ward, *J. Franklin Inst.* **222,** 563 (1936); **224,** 583 and 697 (1937).
[2] Deanesly and Carleton, *loc. cit.* See also Kauffmann, *Relation between Physical Properties and Chemical Constitution,* Ferdinand Enke, Stuttgart (1920).
[3] Pawlow, *Ann.* **196,** 126 (1879).
[4] Boord, *Science of Petroleum* **II,** 1349 (1938).
[5] Edgar and Calingaert, *J. Am. Chem. Soc.* **51,** 1540 (1929).

# Method for Analyzing the Gasoline Fraction of Petroleum, With Preliminary Results on East Texas and Oklahoma Crudes

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**THIS paper gives a general description of a method for analyzing the gasoline fraction of petroleum with respect to the main hydrocarbon components. The results of a test experiment on a mixture of 17 known hydrocarbons (6 paraffins, 4 naphthenes or cyclo-paraffins, and 7 aromatics) normally boiling in the range from 60 to 174° C, are presented, together with preliminary results on the naphtha fractions from East Texas and Oklahoma crude petroleums.**

**This paper was presented to the Division of Refining, before the Twenty-third Annual Meeting of the American Petroleum Institute, Chicago, November 10, 1942.**

FOR ABOUT 15 years API Research Project 6 has been exhaustively separating one crude petroleum, by distillation, extraction, adsorption, and crystallization, and to date has separated a total of 69 hydrocarbons from the gas, gasoline, and kerosine fractions, together with a large number of "homogeneous" fractions from the lubricant portion.[1, 7] The knowledge of the hydrocarbons in petroleum obtained in this comprehensive investigation is providing a basis or framework by means of which less extensive and more rapid analyses of other crude petroleums can be made to yield, with regard to the hydrocarbon constituents, information which otherwise would not be obtainable.

In 1941 the Advisory Committee for API Research Project 6 [J. Bennett Hill, Sun Oil Company, chairman; William J. Sweeney, Standard Oil Development Company; Seymour W. Ferris, The Atlantic Refining Company] recommended that a survey be started by the project on the analysis of the gasoline fraction of representative crude petroleums from various fields. All of the experience and knowledge gained in the comprehensive investigation on the one crude petroleum was to be brought to bear on this new problem, in order to bring forth in a relatively short time fruitful information on the hydrocarbons in the gasoline fraction of the selected petroleums. Within the past year the project has developed a method of analysis for this work which it is hoped will have application beyond the bounds of the present investigation. This paper briefly describes the method, and gives some preliminary results on East Texas and Oklahoma crudes.

The method consists essentially in applying the fractionating processes of adsorption and distillation to the naphtha fraction. The process of adsorption is used to separate from the naphtha fraction a portion containing the aromatic hydrocarbons and a portion containing the paraffins and naphthenes. Then the process of distillation is used to resolve each of these two portions separately.

By adsorption, the napththa is first separated into two portions: one containing the aromatic hydrocarbons, together with the non-hydrocarbons components; and the other, the paraffins and naphthenes. From the first portion, the small amount of non-hydrocarbon components (principally sulfur compounds) are separated by further adsorption to give a clean aromatic portion. Then the clean aromatic portion and the paraffin-naphthene portion separately are subjected to an analytical distillation at a high reflux ratio in a column of high efficiency and low holdup. The boiling point of the distillate is observed as a function of its volume. The distillate is collected in fractions as small as practicable, and the refractive index of each fraction is determined. When necessary for further identification, the density is determined (by combining two or more adjacent fractions, if necessary).

The determination of the main hydrocarbon components in the respective aromatic and paraffin-naphthene portions is based upon a comparison of the boiling point, refractive index and, when necessary, the density of the fractions of distillate with those of appropriate pure compounds.

It is important to note that the distillation of the aromatic hydrocarbons separately from the paraffins and naphthenes, as outlined hereinbefore, not only

makes much easier the determination of the main aromatic compounds, but also immensely improves the resolution of the main components in the paraffin-naphthene portion. This improvement results partly from the reduction in the number of compounds in the mixture being distilled, but mainly from the fact that the relations of vapor pressure and temperature are much more homogeneous for the aromatic portion and for the paraffin-naphthene portion separately than for the original mixture of the two portions.

The separation of the naphtha into an aromatic portion and a paraffin-naphthene portion by the process of adsorption requires only one or two days, depending upon the amount of the aromatics to be separated. On the other hand, the analytical distillation of the two separated portions may be made to require as little as two or three days, or as much as two or three months, depending on the extent to which the resolution by distillation is to be carried; i.e., the time required for the analysis of naphthas by this method will vary from about one week per naphtha for a routine method wherein it is desired to obtain sufficient information for the intelligent immediate utilization of the material in plant processing, to two or three months per naphtha for a research method wherein it is desired to learn as much as possible about the individual components of the material from the standpoint of long-range planning for its utilization.

### Procedure of the Present Investigation

In the present investigation the amount of the naphtha selected for processing is such as to produce not less than about 600 ml of an aromatic portion and not less than about 3600 ml of a paraffin-naphthene portion. Then each of these two portions in the amounts stated is subjected to an efficient analytical distillation. The distillate is collected in fractions of 6 ml, each representing about 1/100 of the aromatic portion and about 1/600 of the paraffin-naphthene portion. For each fraction, determination is made of the refractive index, $N_D$. When necessary for further identifiaction, two consecutive fractions are combined for measurement of the density, by means of a specific-gravity balance which requires a minimum volume of 10 ml and which has a precision of $\pm 0.00003$ gram per milliliter.

The process of adsorption used in the present investigation to separate and recover the aromatic hydrocarbons from the paraffins and naphthenes is an improved modification of that described in earlier papers of the project.[2, 3] The new procedure is given in detail in a recently completed report[4] of the project which, during the war period, is available for restricted distribution to the American Petroleum Institute and United States government laboratories and, on application, to other appropriate groups. As mentioned in the preceding section, the small amount of sulfur and other non-hydrocarbon compounds, which in the first adsorption are separated with the aromatic hydrocarbons, then are removed (together with a small amount of aromatic hydrocarbons) from the "aromatic" portion by further adsorption to produce a clean aromatic portion for distillation.

The analytical distillations of the aromatic and the paraffin-naphthene portions obtained in the present investigation are being performed in the two columns whose operating characteristics are given in Table 1. Still "O" is being used on the aromatic portion and still "P" on the paraffin-naphthene portion. The assembly, testing, and operation of these rectifying columns will be described in a separate publication.[5] As can be seen from the data given in Table 1, the time required for the distillation of the aromatic portion is nearly one month, with continuous operation 24 hours per day, 7 days per week; and the time required for the distillation of the paraffin-naphthene portion is more than 2 months with similar continuous operation. By such distillation it is possible to separate effectively a considerable number of individual components in one distillation.

In the distillation of the aromatic portion (see Figure 5, for example) each of the 8 possible aromatic compounds normally boiling below 160° C. can be resolved with the exception of *p*xylene and *m*xylene, which normally boil only 0.8° C. apart near 139° C. Fortunately, however, the composition of the mixture of *p*xylene and *m*xylene can be determined readily from a measurement of its freezing point.* Above 160° C., the number of possible aromatic compounds increases rapidly, and the extent of the analysis which is possible will depend upon the number of close-boiling neighbors, and upon the difference in their refractive indices and densities.

In the distillation of the paraffin-naphthene portion (see Figure 4, for example) it is likewise possible to resolve a number of individual components in the one distillation. Excluding *cis* - 1,2 - dimethylcyclopentane near 99° C., *cis*-1,3-dimethylcyclopentane near the same temperature, 2,2,3-trimethylbutane at 80.9° C., and 2,2,4-trimethylpentane at 92.2° C.—no one of which has yet been found in any petroleum†—there are 20 possible paraffin and naphthene (cyclopentane and cyclohexane derivatives) hydrocarbons normally boiling in the range from 40 to 102° C. These are as follows:

| COMPOUND | Type | Boiling Point (°C) | |
|---|---|---|---|
| Cyclopentane | Naphthene | 49.5 | B |
| 2,2-Dimethylbutane | Paraffin | 49.8 | |
| 2,3-Dimethylbutane | Paraffin | 58.0 | A |
| 2-Methylpentane | Paraffin | 60.3 | A |
| 3-Methylpentane | Paraffin | 63.3 | A |
| *n*Hexane | Paraffin | 68.7 | A |
| Methylcyclopentane | Naphthene | 71.9 | A |
| 2,2-Dimethylpentane | Paraffin | 79.0 | A |
| 2,4-Dimethylpentane | Paraffin | 80.8 | B |
| Cyclohexane | Naphthene | 80.8 | |
| 3,3-Dimethylpentane | Paraffin | 86.0 | A |
| 1,1-Dimethylcyclopentane | Naphthene | 87.5 | A |
| 2,3-Dimethylpentane | Paraffin | 89.8 | |
| 2-Methylhexane | Paraffin | 90.0 | |
| *trans*-1,3-Dimethylcyclopentane | Naphthene | 90.9 | C |
| *trans*-1,2-Dimethylcyclopentane | Naphthene | 91.9 | |
| 3-Methylhexane | Paraffin | 92.0 | |
| 3-Ethylpentane | Paraffin | 93.5 | A |
| *n*Heptane | Paraffin | 98.4 | A |
| Methylcyclohexane | Naphthene | 100.9 | A |

A distillation column having a separating efficiency near 120 theoretical plates can effect a separation of 2 hydrocarbons normally boiling as little as 1.5° C. apart. One distillation in such a column of a mixture containing all of the foregoing 20 components would yield the following results: the 11 compounds marked "A" would be substantially separated as individual components; the 2 pairs marked "B" would be binary mixtures each containing a paraffin and a naphthene hydrocarbon of about the same boiling point, the relative amounts of which

* The freezing points are +13.2° for *p*xylene, and —47.9° C for *m*xylene.

† It is likely that every petroleum contains at least a minute amount of nearly every possible paraffin, naphthene, or aromatic hydrocarbon. Fortunately, however, the bulk of the gasoline fraction of Mid-Continent petroleum, and to a greater or lesser extent other crudes, is made up of a relatively small number of compounds.[1] If found in petroleum in any significant amount, the two *cis*-dimethylcyclopentanes mentioned previously likely would appear in a naphtha very rich in naphthenes, and the two trimethyl paraffins in a naphtha very rich in *iso*-paraffins.

**TABLE 1**

**Approximate Operating Characteristics of the Two Analytical Distillation Columns**

| Designation of Still | "O" | "P" |
|---|---|---|
| Rectifying section: | | |
| Diameter, mm | 10 | 13 |
| Length, mm | 1,830 | 1,830 |
| Packing | Steadman | Heli-Grid |
| Operating throughout (liquid), ml per hour | About 150 | About 250 |
| Operating holdup (liquid), ml | About 25 | About 30 |
| Operating pressure drop, mm of mercury | 18 | 10 |
| Reflux ratio | 120 to 1<br>150 to 1 | 120 to 1<br>150 to 1 |
| Rate of removal of distillate (liquid), ml per hour | 1 | 2 to 2½ |
| Nature of charge | Aromatic | Paraffin-naphthene |
| Volume of charge, ml | 600 | 3,600 |
| Time of distillation, hours | 600 | 1,600 |
| Pressure, mm of mercury | 770 | 770 |

could be determined readily from the refractive index or density or both; the mixture of 5 hydrocarbons marked "C" would not be resolvable in the one distillation, but the relative amounts of paraffins and naphthenes could be determined readily from the refractive index and density. It is interesting to note that all of the 20 hydrocarbons listed previously herein have been isolated from petroleum[1, 8, 9] with the exception of the following four compounds: 2,4-dimethylpentane at 80.8° C.; 3,3-dimethylpentane at 86.0° C.; 2,3-dimethylpentane at 89.8° C.; and 3-ethylpentane at 93.5° C.

| MATERIAL | Aromatics | Paraffins + Naphthenes | Total |
|---|---|---|---|
| Charged | 624.91 grams<br>35.69 percent | 1,126.01 grams<br>64.31 percent | 1,750.92 grams<br>100.00 percent |
| Recovered | 617.71 grams<br>35.28 percent | 1,099.66 grams<br>62.80 percent | 1,717.37 grams<br>98.08 percent |
| Loss | 7.20 grams<br>0.41 percent | 26.35 grams<br>1.51 percent | 33.55 grams<br>1.92 percent |

## Test of the Method With a Mixture of Known Hydrocarbons

In order to establish the reliability of this method of analysis, and to learn something of the amount of loss of material in processing, a test mixture of 17 known hydrocarbons, normally boiling in the range from 60 to 174° C., was prepared quantitatively by weight. The mixture had a volume of about 2.3 liters, and consisted of 6 paraffin, 4 naphthene, and 7 aromatic hydrocarbons.

This mixture was separated by the process of adsorption into two lots: one containing the aromatic hydrocarbons, and the other containing the paraffins and naphthenes. Each lot then was subjected to an analytical distillation. An indication of the completeness of the separation, and of the amount of material lost during the processes of adsorption and distillation, is given by the summary at the bottom of this page.

If the amounts of aromatics and of paraffins plus naphthenes lost in the two fractionating processes are approximately in the same ratio as their percentages in the original mixture, the composition of the material recovered will be, on a percentage basis, the same as that of the material charged. The extent to which this was true in the foregoing experiment is indicated by the following figures giving percentages by weight:

| MATERIAL | Aromatics (Percent by Weight) | Paraffins + Naphthenes (Percent by Weight) | Total (Percent by Weight) |
|---|---|---|---|
| Original | 35.69 | 64.31 | 100.00 |
| Product | 35.97 | 64.03 | 100.00 |
| Difference | +0.28 | −0.28 | ..... |

Because the distilling columns described in Table 1 had not yet been assembled, the two portions of the test mixture were distilled separately in a column, with the following operating characteristics: rectifying section, 15 mm in diameter and 2800 mm in length; operating throughput, 750 ml of liquid per hour; separating efficiency at the operating throughput, near 110 theoretical plates; operating holdup, about 75 ml of liquid; reflux ratio, 120. The values of boiling point and refractive index of the distillate, as a function of its volume and mass, showed in the case of both portions excellent accord with the known composition of the material.

Figure 1 gives a plot of the volume-temperature relation for the distillation of the aromatic portion. Figure

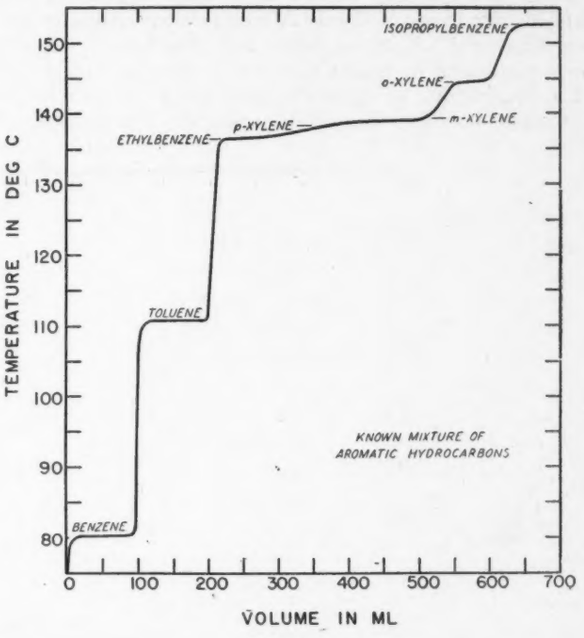



**FIGURE 1**

**Plot of the Boiling Point as a Function of Volume for the Distillation (at a Controlled Pressure of 770 Mm Mercury) of the Aromatic Hydrocarbons from the Known Test Mixture**

2 gives a similar plot for the paraffin-naphthene portion, together with a plot of the refractive index as a function of the volume of distillate. The appropriate compounds are indicated on the charts. Table 2 compares the known composition of the material charged into the adsorption process with the analysis of the product from the distillation process.

## Preliminary Results on East Texas Naphtha

The East Texas naphtha was provided by the Standard Oil Development Company. Batch-distillation data

**TABLE 2**

**Analytical Data on the Test Mixture of 17 Known Hydrocarbons Before and After Processing**

| COMPOUND | Boiling Point (Deg. C) | Percentage by Weight of Charge | Percentage by Weight of Product | Difference (Percent) |
|---|---|---|---|---|
| 2-Methylpentane | 60.3 | 3.30 | 3.58 | +0.28 |
| *n*Hexane | 68.7 | 5.56 | 5.10 | −0.46 |
| Benzene | 80.1 | 4.94 | 5.10 | +0.16 |
| Cyclohexane | 80.8 | 9.08 | 8.86 | −0.22 |
| *n*Heptane | 98.4 | 7.59 | 7.82 | +0.23 |
| Methylcyclohexane | 100.9 | 8.08 | 7.99 | −0.09 |
| Toluene | 110.6 | 5.37 | 5.26 | −0.11 |
| *n*Octane | 125.6 | 6.03 | 6.10 | +0.07 |
| Ethylcyclohexane | 131.8 | 3.55 | 3.58 | +0.03 |
| Ethylbenzene | 136.2 | 4.99 | 4.59 | −0.40 |
| *p*Xylene | 138.4 | 5.11 | 10.51 | +0.32 |
| *m*Xylene | 139.2 | 5.08 | | |
| *o*Xylene | 144.4 | 4.22 | 4.16 | −0.06 |
| *n*Nonane | 150.7 | 6.31 | 6.11 | −0.20 |
| isoproprylbenzene | 152.4 | 5.98 | 6.39 | +0.41 |
| *n*Prophycyclohexane | 156.7 | 6.58 | 6.65 | +0.07 |
| *n*Decane | 174.0 | 8.23 | 8.20 | −0.03 |
| Total | .... | 100.00 | 100.00 | .... |
| Average Difference | ..... | ..... | ..... | ±0.20 |

on the crude petroleum were reported by them as follows:

| | Percentage of Crude (By Volume) | Aniline Point (°F.) | Gravity (API) |
|---|---|---|---|
| $C_4$ fraction | 0 to 1.0 | .... | .... |
| $C_5$ fraction | 1.0 to 3.3 | .... | .... |
| Light naphtha | 3.3 to 14.3 | 128 | 66.6 |
| Heavy naphtha | 14.3 to 38.8 | 126 | 50.8 |

Data on the Engler distillation for the light and heavy naphtha are given in Table 3. For this investigation, the "depentanized" light naphtha and the heavy naphtha were combined in the production proportion of 11.0 to 24.5, by volume, to make the total East Texas naphtha for analysis. The material examined represented 35

**TABLE 3**

**Assay Distillation (Engler) of the East Texas Light and Heavy Naphthas (Data Provided by the Standard Oil Development Company)**

| LIGHT NAPHTHA (DEPENTANIZED) | | HEAVY NAPHTHA | |
|---|---|---|---|
| Percentage | Temperature (°F) | Percentage | Temperature (°F) |
| Initial | 136 | Initial | 248 |
| 2.5 | 158 | 2.0 | 257 |
| 37.0 | 176 | 7.0 | 266 |
| 77.0 | 194 | 27.5 | 284 |
| 98.0 | 212 | 47.0 | 302 |
| Final | 216 | 62.5 | 320 |
| | | 74.0 | 338 |
| | | 82.5 | 356 |
| | | 90.0 | 372 |
| | | 91.0 | 374 |
| | | 96.0 | 392 |
| | | Final | 399 |

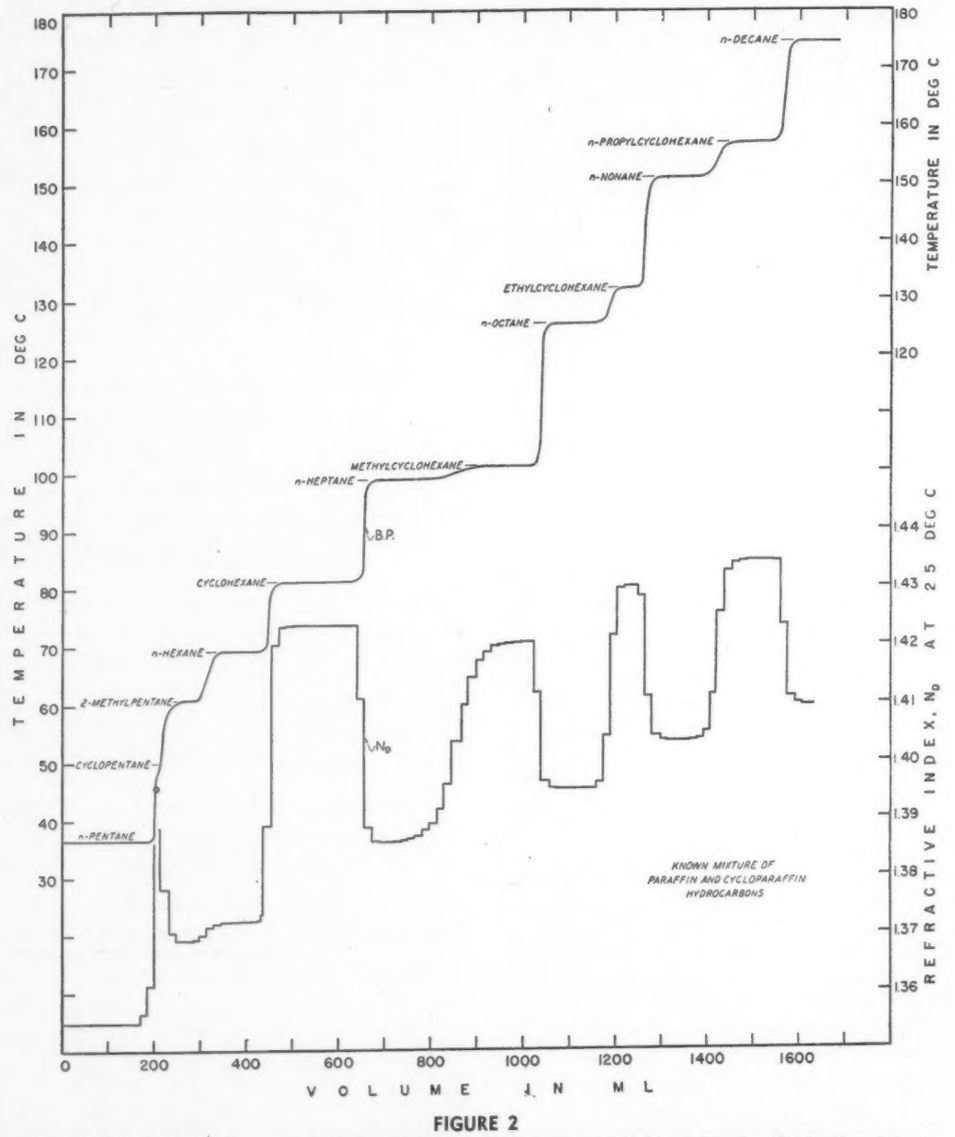



**FIGURE 2**

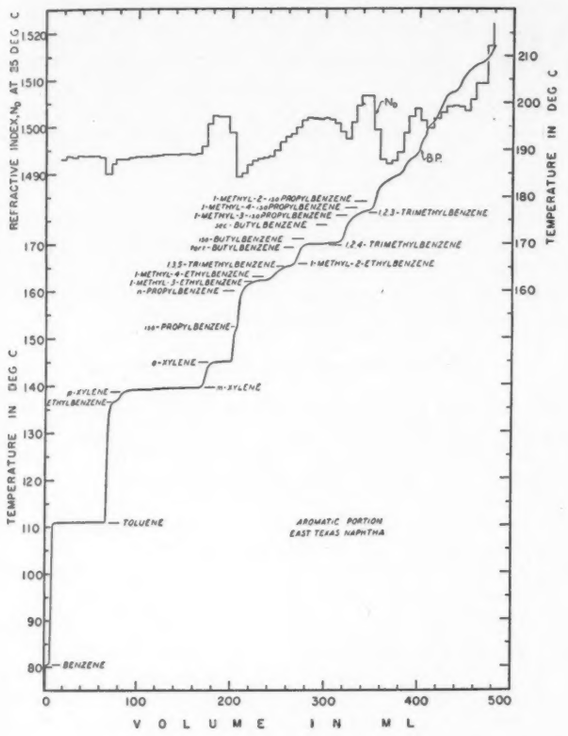
**Plot of the Boiling Point and Refractive Index as a Function of Volume for the Distillation (at a Controlled Pressure of 770 Mm Mercury) of the Paraffin and Naphthene Hydrocarbons from the Known Test Mixture.**

percent by volume of the crude petroleum. By a method[6] developed recently in the work of API Research Project 6, the amount of aromatic hydrocarbons in this East Texas naphtha was found to be 10.1 percent by volume. The sulful content of the naphtha was 0.033 percent by weight.*

In the manner previously described, the naphtha was separated into an aromatic portion and a paraffin-naph-

* Determined under the supervision of R. C. Hardy in the Section on Lubrication and Liquid Fuels at the National Bureau of Standards.

thene portion. The aromatic portion was distilled in still "O," which is described in Table 1. Figure 3 shows the boiling point and the refractive index of the distillate from the aromatic portion as a function of its volume. The paraffin-naphthene portion is being distilled in still "P," which is described in Table 1. Figure 4 shows the boiling point and the refractive index of the first part of the distillate (to 103° C.) from the paraffin-naphthene portion as a function of its volume. Although the data have not yet been reduced to final




For reference, the boiling points of all the possible aromatic hydrocarbons normally boiling below 180° C. are indicated. The data represented here, plus a determination of the freezing point of the mixture of *p*xylene and *m*xylene, will serve readily to determine the amounts each of benezene, toluene, ethylbenzene, *p*xylene, *m*xylene, *o*xylene, *iso*propylbenzene, and *n*propylbenzene. Above 160° C., the number of possible aromatic compounds increases rapidly, and the analysis with respect to individual compounds becomes more difficult and less certain (see text).

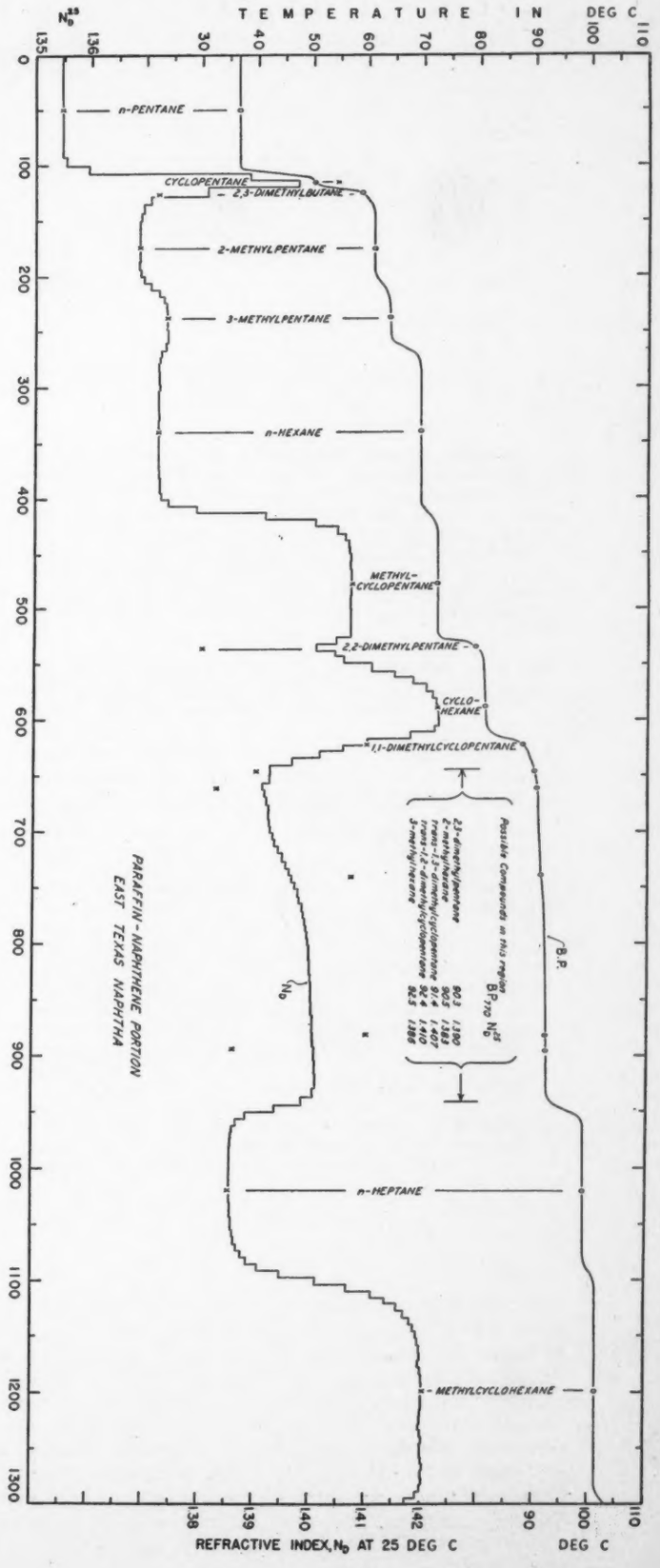
**FIGURE 3**

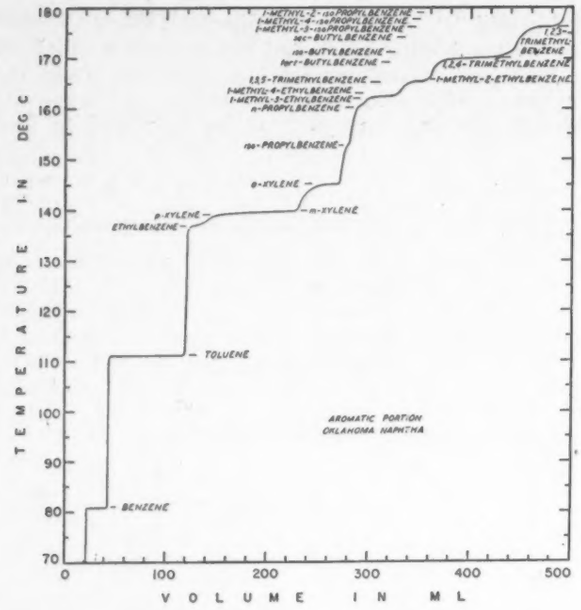
**Plot of the Boiling Point and Refractive Index as a Function of Volume, for the Distillation (at a Controlled Pressure of 770 Mm Mercury) of the Aromatic Hydrocarbons from the East Texas Naphtha**

At the time this plot was made, the distillation was about one third completed. The circles and crosses represent, respectively, the boiling points (at 770 mm mercury) and the refractive indices ($n_D$ at 25° C.) of the indicated compounds in the pure state. The data represented here will serve readily to determine the amounts each of *n*pentane, cyclopentane, 2,3-dimethylbutane, 2-methylpentane, 3-methylpentane, *n*hexane, methylcyclopentane, 2,2-dimethylpentane, cyclohexane, 1,1-dimethylcyclopentane, *n*heptane, and methylcyclohexane. It is seen that the material of the range 90 to 93° C. (at 770 mm mercury) is complicated by the presence of several close-boiling paraffin and naphthene compounds.

**FIGURE 4**

**Plot of the Boiling Point and Refractive Index as a Function of Volume, for the Distillation (at a Controlled Pressure of 770 Mm Mercury) of the Paraffin and Naphthene Hydrocarbons from the East Texas Naphtha**






For reference, the boiling points of all the possible aromatic hydrocarbons normally boiling below 180° C. are indicated. The data represented here, plus a determination of the freezing point of the mixture of *p*xylene and *m*xylene, will serve readily to determine the amounts each of benzene, toluene, ethylbenzene, *p*xylene, *m*xylene, *o*xylene, *iso*propylbenzene, and *n*propylbenezene. Above 160° C., the number of possible aromatic compounds increases rapidly, and the analysis with respect to individual compounds becomes more difficult and less certain (see text).

**FIGURE 5**

**Plot of the Boiling Point as a Function of Volume, for the Distillation (at a Controlled Pressure of 770 Mm Mercury) of the Aromatic Hydrocarbons from the Oklahoma Naphtha**

form, the following approximate figures will give an indication of the amounts of some of the hydrocarbons in this East Texas naphtha, in percentage by volume:

| | | | |
|---|---|---|---|
| Benzene | 0.1 | Cyclopentane | 0.3 |
| Toluene | 1.3 | 2,3-Dimethylbutane | 0.3 |
| Ethylbenzene | 0.4 | 2-Methylpentane | 2 |
| *p*Xylene, *m*Xylene | 1.6 | 3-Methylpentane | 1½ |
| | | *n*Hexane | 4 |
| *o*Xylene | 0.6 | Methylcyclopentane | 3 |
| *Iso*propylbenzene | 0.1 | 2,2-Dimethylpentane | 0.2 |
| *n*Propylbenzene | 0.1 | Cyclohexane | 2 |
| | | 1,1-Dimethylcyclopentane | 0.2 |
| | | *n*Heptane | 4 |
| | | Methylcyclohexane | 5 |

## Preliminary Results on Oklahoma Naphtha

The Oklahoma naphtha being analyzed is from the original Mid Continent petroleum that has been under extended investigation by the project. The assay properties of this petroleum have been given previously.[7] For this investigation, a naphtha fraction was made by taking that part of the crude coming over as distillate between 46 and 180° C. in a column of nearly 100 theoretical plates operated at a reflux ratio of about 15 to 1. This portion represented 35 percent by volume of the original petroleum. The aromatic content of this naphtha was found to be 9.3 percent by volume, and the sulfur content 0.017 percent by weight (see preceding section).

As before, the naphtha fraction was separated into an aromatic portion and a paraffin-naphthene portion. The aromatic portion was distilled in still "O." Figure 5 shows the boiling point of the distillate from the aromatic portion as a function of its volume.

## Crude Petroleums to Be Analyed

In addition to the East Texas and Oklahoma crudes described in this paper, which are intermediate in type, the Advisory Committee has selected the following crudes as next to be analyzed by this method:

| Type | Field |
|---|---|
| High aromatic | Conroe, Texas |
| High paraffin, low naphthene | Greendale-Kawkawlin, Michigan |
| High *iso*paraffin | Winkler, Texas |
| High naphthene | Midway, California |
| High paraffin, low aromatic | Pennsylvania |

## References


[1] F. D. Rossini, *Proc. API* **18 [III]** 36 (1937); *Oil Gas J.* **36 [26]** 193 (1937); *Refiner Natural Gasoline Mfr.* **16 [11]** 545 (1937).

[2] B. J. Mair and J. D. White. *J. Research Natl. Bur. Standards* **15**, 51 (1935).

[3] C. B. Willingham, *J. Research Natl. Bur. Standards* **22**, 321 (1939).

[4] B. J. Mair and A. F. Forziati, restricted report (1942) of *API Research Project 6* on the separation of aromatic hydrocarbons.

[5] C. B. Willingham and F. D. Rossini, *API Research Project 6.*

[6] B. J. Mair and A. F. Forziati, restricted report (1942) of *API Research Project 6* on the analytical determination of aromatic hydrocarbons.

[7] F. D. Rossini, *Proc. API* **19 [III]** 99 (1938); *Oil Gas J.* **37 [27]** 141 (1938); *Refiner Natural Gasoline Mfr.* **17 [11]** 557 (1938).

[8] M. M. Hicks-Bruun, J. H. Bruun, and W. B. M. Faulconer, *J. Am. Chem. Soc.* **61**, 3099 (1939).

[9] M. R. Fenske, private communication (regarding 2,2-dimethylbutane).

# Synthesis and Properties of Hydrocarbons of High Molecular Weight

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C. H. HERR,
The Pennsylvania State College

THE work during the past year of American Petroleum Institute Research Project 42 at The Pennsylvania State College on the synthesis and properties of hydrocarbons of high molecular weight is summarized in this paper.

Twenty new hydrocarbons ranging in molecular weight from 336 to 434 have been prepared, making a total of 42 hydrocarbons of high molecular weight having a purity of 95 mole percent, or better, that thus far have been reported by this project. The physical properties determined for each of the hydrocarbons are as follows:

1. Kinematic viscosity at 32, 68, 100, 140, and 210° F; Saybolt Universal viscosity calculated for 100 and 210° F.
2. Kinematic viscosity index by the Dean and Davis method.
3. Density at 32, 68, 100, 140, and 210° F; gravity in degrees API, calculated.
4. Melting point from the melting curve.
5. Boiling point at 0.50 mm and 1.00 mm from vapor-pressure curve over the range 0.50 mm to 10.0 mm.
6. Heat of vaporization, calculated for the range 0.50 mm to 10.0 mm pressure.
7. Aniline point, reported in degrees C and degrees F.
8. Refractive index at 20, 30, and 40° C.
9. Specific and molecular refraction, calculated for 20° C.
10. Molecular volume, calculated for 20° C.

These data have been employed in checking the work of Kurtz and Lipkin on molecular volume, and the method for calculating refractive index of Lipkin and Martin. Several procedures for the estimation of the relative structure of hydrocarbon mixtures are examined. In addition, the work completed on three binary systems of the pure hydrocarbons is reported.

Tentative generalizations regarding the effect of chemical structure on physical properties have been drawn.

This paper was presented to the Division of Refining, before the Twenty-third Annual Meeting of the American Petroleum Institute, Chicago, November 10, 1942.

RESEARCH PROJECT 42* of the American Petroleum Institute was placed at The Pennsylvania State College for the preparation and study of pure hydrocarbons of high molecular weight. The project rapidly is building a "bank" of hydrocarbons ranging from 25 to 60 carbon atoms, and carefully is compiling their physical properties.

The need for research of this nature is evident. It should permit better conclusions concerning the chemical composition of lubricating oils, should clarify the variation of physical properties with chemical structure of hydrocarbons in the lubricating-oil range, and should supply accurate information required for physico-chemical calculations. Further, the data thus compiled should prove particularly valuable in the field of special oils. Reliable methods for the preparation and purification of hydrocarbons in this range are being developed.

The results of the first 16 months were summarized in the first paper of this series,[1] which was presented at the Twenty-second Annual Meeting of the American Petroleum Institute in San Francisco. At that time the syntheses and properties of 22 hydrocarbons, containing from 25 to 32 carbon atoms, were reviewed. The present discussion deals with the continuation of the work. The initial program on the *iso*paraffins in the lower range almost has been completed. A systematic study of the influence of position of phenyl and cyclohexyl nuclei on a paraffinic straight chain has yielded very interesting results. The effect on physical properties of the number of cyclic nuclei in a molecule is incomplete at this time, but the data at hand are revealing. Basic work on the relative effects of cyclohexyl and cyclopentyl nuclei is in progress, that completed being included in this paper. The preliminary investigation of the higher-molecular-weight range (50 carbon atoms) is in progress; and a study of multi-ring compounds, fused and non-fused, is under way.

In addition, the project has begun a study of the physical properties of binary mixtures of the pure compounds now available. The various physical properties of the three binary systems thus far investigated are tabulated and discussed.

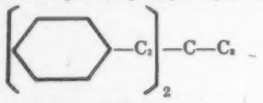
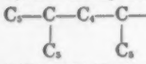
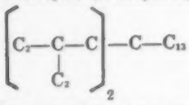
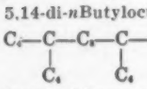
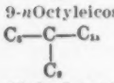
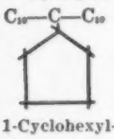
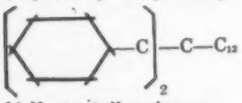
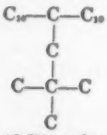
The staff of Project 42 has completed considerable preliminary research on the use of viscosity as a criterion of uniformity of composition. Some of the more interesting and informative results are reported herein.

* Frank C. Whitmore, director; Advisory Committee: L. C. Beard Jr. (chairman), George Calingaert, L. M. Henderson, and L. A. Mikeska.

## History

The historical discussion of the subject was well covered in the first paper of this series.[1] For a very complete treatment the reader is referred to the paper of Mikeska.[2] Within the last year two publications of interest have appeared. Neyman-Pilat and Pilat[9] describe 7 new 22-carbon-atom hydrocarbons, both aromatic and naphthenic, studied by them. Based on the properties of these compounds and several others taken from the literature, these authors have made generalizations as to the effect of structure on physical properties. Several

**TABLE 1**

| PSC No. | Name of Structure | Empirical Formula | Theoretical Molecular Weight | Kinematic Viscosity (Centistokes) at: 32 Deg F | 68 Deg F | 100 Deg F | 140 Deg F | 210 Deg F | Calculated Saybolt Universal Viscosity (Seconds) at: 100 Deg F | 210 Deg F | Kinematic Viscosity Index (Dean and Davis) | Aniline Point: Deg C | Deg F |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 18. | 1-Phenyl-3-(2-phenylethyl)-hendecane  | $C_{25}H_{36}$ | 336.5 | 81.23 | 26.27 | 12.61 | 6.46 | 2.88 | 68.3 | 35.8 | 77.5 | | |
| 22. | 6,11-di-*n*Amylhexadecane  | $C_{26}H_{54}$ | 366.7 | 65.50 | 23.78 | 11.80 | 6.16 | 2.74 | 65.2 | 35.4 | 72.0 | 112.0 | 233.6 |
| 23. | 3-Ethyl-5-(2-ethylbutyl)-octadecane  | $C_{26}H_{54}$ | 366.7 | 63.30 | 23.13 | 11.84 | 6.27 | 2.89 | 65.3 | 35.9 | 102 | 112.1 | 233.8 |
| 55. | 5,14-di-*n*Butyloctadecane  | $C_{26}H_{54}$ | 366.7 | 72.8* | 24.49 | 12.18 | 6.31 | 2.85 | 66.6 | 35.7 | 84.0 | 111.3 | 232.3 |
| 63. | 9-*n*Octyleicosane  | $C_{28}H_{58}$ | 394.7 | 60.2* | 22.39 | 12.03 | 6.54 | 3.10 | 66.0 | 36.5 | 135 | 117.2 | 243.0 |
| 64. | 11-Cyclopentylheneicosane  | $C_{26}H_{52}$ | 364.7 | 63.65 | 24.35 | 12.53 | 6.71 | 3.10 | 68.0 | 36.5 | 122 | 106.5 | 223.7 |
| 65. | 1-Cyclohexyl-2-(cyclohexylmethyl)-pentadecane  | $C_{25}H_{54}$ | 390.7 | 500* | 106.98 | 40.27 | 16.26 | 5.63 | 187.1 | 44.6 | 81.0 | 105.1 | 221.2 |
| 67. | 11-Neopentylheneicosane  | $C_{26}H_{54}$ | 366.7 | 60.07 | 22.64 | 11.71 | 6.26 | 2.89 | 64.9 | 35.9 | 106 | 114.9 | 238.8 |
| 68. | 13-Phenylpentacosane | $C_{31}H_{56}$ | 428.8 | 140.5* | 45.5* | 21.69 | 10.76 | 4.49 | 184.7 | 41.0 | 139 | 79.4 | 174.9 |
| 69. | 13-Cyclohexylpentacosane | $C_{31}H_{62}$ | 434.8 | 154.4 | 51.64 | 24.05 | 11.61 | 4.78 | 114.9 | 41.9 | 135 | 115.5 | 239.9 |
| 75. | 3-Cyclohexyleicosane | $C_{26}H_{52}$ | 364.7 | 84.5* | 31.36 | 15.96 | 8.42 | 3.85 | 81.0 | 39.0 | 156 | 107.7 | 225.9 |

[a] Solution freezes above aniline point.
* Extrapolation values.

**TABLE 1—Continued**

| Density (Grams Per Milliliter) | | | | | Gravity (Deg API) | Melting Point (Deg C) | Boiling Point (Deg C) | | Heat of Vaporization (Gallons Per Gram) | Refractive Index ($n^t D$) | | | | Molecular Refraction | | Specific Refraction | Molecular Volume | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 32 Deg F | 68 Deg F | 100 Deg F | 140 Deg F | 210 Deg F | | | 0.50 Mm | 1.00 Mm | | 20.0 Deg C (Calculated) | 20.0 Deg C | 30.0 Deg C | 40.0 Deg C | Extrapolated | Calculated | | Extrapolated | Calculated |
| 0.9356 | 0.9211 | 0.9093 | 0.8948 | 0.8689 | 21.5 | Liquid −60 | 184 | 197 | 66 | | 1.5192 | 1.5154 | 1.5116 | 110.9 | 110.4 | 0.3296 | 365.3 | .... |
| 0.8208 | 0.8068 | 0.7952 | 0.7799 | 0.7549 | 42.2 | −16.2 | 169 | 182 | 58 | 1.4503 | 1.4502 | 1.4464 | 1.4426 | 122.0 | 122.3 | 0.3332 | 454.5 | 454.5 |
| 0.8249 | 0.8109 | 0.7998 | 0.7850 | 0.7595 | 42.3 | Glass | 167 | 180 | 57 | 1.4526 | 1.4521 | 1.4482 | 1.4445 | 121.8 | 122.3 | 0.3327 | 452.2 | 454.5 |
| 0.8206* | 0.8075 | 0.7968 | 0.7814 | 0.7555 | 42.9 | 5.7 | 172 | 185 | 58 | 1.4508 | 1.4508 | 1.4469 | 1.4430 | 122.0 | 122.3 | 0.3333 | 454.1 | 454.5 |
| 0.8203* | 0.8074 | 0.7959 | 0.7813 | 0.7564 | 43.0 | 0.5 | 199 | 211 | 64 | 1.4513 | 1.4515 | 1.4477 | 1.4440 | 131.5 | 131.5 | 0.3338 | 488.9 | 487.0 |
| 0.8466 | 0.8329 | 0.8213 | 0.8073 | 0.7823 | 37 7 | −12.7 | 185 | 199 | 60 | 1.4620 | 1.4613 | 1.4575 | 1.4538 | 120 0 | 120.1 | 0.3296 | 437.9 | 438.8 |
| 0.8755* | 0.8632 | 0.8518 | 0.8378 | 0.8135 | 31.8 | 1.7 | 202 | 215 | 64 | 1.4761 | 1.4747 | 1.4710 | 1.4674 | 127.1 | 127.1 | 0.3260 | 452.6 | 449.5 |
| 0.8160 | 0.8029 | 0.7915 | 0.7774 | 0.7525 | 44.0 | −21.0 | 176 | 189 | 60 | 1.4496 | 1.4491 | 1.4453 | 1.4416 | 122.3 | 122.3 | 0.3341 | 456 7 | 454.5 |
| 0 8668* | 0.8539* | 0.8424 | 0.8278 | 0.8030 | 33.5 | 31.7 | 220 | 235 | 53 | .... | 1 4787 | 1 4750 | 1 4713 | 142.0 | 141.8 | 0.3320 | 502.3 | .... |
| 0.8529 | 0.8390 | 0.8282 | 0.8137 | 0 7856 | 36.4 | 1.2 | 220 | 235 | 53 | 1 4656 | 1.4653 | 1.4615 | 1.4578 | 143 1 | 143.2 | 0.3297 | 518.2 | 517.1 |
| 0.8510* | 0.8383 | 0.8268 | 0.8130 | 0.7882 | 36.6 | 22.7 | 191 | 205 | 61 | 1.4651 | 1.4642 | 1.4605 | 1.4568 | 119.9 | 120.1 | 0.3293 | 435.0 | 435.7 |

* Extrapolation values.

**TABLE 1—Continued**

| PSC No. | Name of Structure | Empirical Formula | Theoretical Molecular Weight | Kinematic Viscosity (Centistokes) at: 32 Deg F | 68 Deg F | 100 Deg F | 140 Deg F | 210 Deg F | Calculated Saybolt Universal Viscosity (Seconds) at: 100 Deg F | 210 Deg F | Kinematic Viscosity Index (Dean and Davis) | Aniline Point Deg C | Deg F |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 76. | 5-Cyclohexyleicosane<br>$C_6—C—C_{13}$<br> | $C_{26}H_{52}$ | 364.7 | 105.95 | 36.35 | 17.44 | 8.71 | 3.76 | 87.0 | 38.7 | 119 | 107.0 | 224.6 |
| 77. | 7-Cyclohexyleicosane<br>$C_6—C—C_{13}$<br> | $C_{26}H_{52}$ | 364.7 | 101.7 | 35.24 | 17.00 | 8.50 | 3.65 | 85.2 | 58.3 | 111 | 106.7 | 224.1 |
| 78. | 9-Cyclohexyleicosane<br>$C_6—C—C_{11}$<br> | $C_{26}H_{52}$ | 364.7 | 95.02 | 33.34 | 16.19 | 8.14 | 3.52 | 81.5 | 37.9 | 107 | 106.4 | 223.5 |
| 79. | 3-Phenyleicosane<br>$C_6—C—C_{17}$<br> | $C_{26}H_{46}$ | 358.6 | 67.0* | 25.4* | 13.54 | 7.32 | 3.39 | 71.8 | 37.5 | 143 | 61.3 | 142.3 |
| 80. | 5-Phenyleicosane<br>$C_6—C—C_{13}$<br> | $C_{26}H_{46}$ | 358.6 | 85.0* | 29.2* | 14.89 | 7.65 | 3.38 | 77.0 | 37.4 | 112 | 61.4 | 142.5 |
| 81. | 7-Phenyleicosane<br>$C_6—C—C_{13}$<br> | $C_{26}H_{46}$ | 358.6 | 87.5* | 28.92 | 14.35 | 7.39 | 3.28 | 74.9 | 37.1 | 108 | 62.2 | 144.0 |
| 82. | 9-Phenyleicosane<br>$C_6—C—C_{11}$<br> | $C_{26}H_{46}$ | 358.6 | 82.0* | 27.86 | 13.90 | 7.18 | 3.20 | 73.2 | 36.9 | 105 | 63.4 | 146.1 |
| 87. | 9-(2-Phenylethyl)-heptadecane<br>$C_8—C—C_9$<br>$C_2$<br> | $C_{25}H_{44}$ | 344.6 | 43.47 | 17.38 | 9.38 | 5.24 | 2.53 | 56.7 | 34.7 | 108 | 53.1 | 127.6 |
| 88. | 9-(2-Cyclohexylethyl)-heptadecane<br>$C_8—C—C_9$<br>$C_2$<br> | $C_{25}H_{50}$ | 350.6 | 83.02 | 29.85 | 14.72 | 7.48 | 3.29 | 76.3 | 37.1 | 101 | 104.8 | 220.6 |

* Extrapolation values.

**TABLE 1—Continued**

| Density (Grams Per Milliliter) | | | | | Gravity (Deg API) | Melting Point (Deg C) | Boiling Point (Deg C) | | Heat of Vaporization (Gallons Per Gram) | Refractive Index ($n^t_D$) (Calculated) | | | | Molecular Refraction | | Specific Refraction | Molecular Volume | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 32 Deg F | 68 Deg F | 100 Deg F | 140 Deg F | 210 Deg F | | | 0.50 Mm | 1.00 Mm | | 20.0 Deg C | 20.0 Deg C | 30.0 Deg C | 40.0 Deg C | Extrapolated | Calculated | | Extrapolated | Calculated |
| 0.8513 | 0.8571 | 0.8266 | 0.8116 | 0.7870 | 36.8 | — 2.2 | 189 | 202 | 64 | 1.4647 | 1.4638 | 1.4600 | 1.4563 | 119.9 | 120.1 | 0.3295 | 435.7 | 435.7 |
| 0.8500 | 0.8367 | 0.8254 | 0.8113 | 0.7865 | 37.0 | Glass | 186 | 200 | 62 | 1.4646 | 1.4635 | 1.4598 | 1.4561 | 119.9 | 120.1 | 0.3295 | 435.9 | 435.7 |
| 0.8499 | 0.8368 | 0.8254 | 0.8111 | 0.7863 | 37.0 | Glass | 186 | 199 | 61 | 1.4643 | 1.4635 | 1.4598 | 1.4561 | 119.9 | 120.1 | 0.3294 | 435.8 | 435.7 |
| 0.8678* | 0.8547* | 0.8432 | 0.8282 | 0.8032 | 33.4 | 29.3 | 188 | 202 | 63 | . . . | 1.4796 | 1.4758 | 1.4720 | 118.9 | 118.7 | 0.3322 | 419.6 | .... |
| 0.8680* | 0.8546* | 0.8430 | 0.8275 | 0.8015 | 33.4 | 30.2 | 184 | 197 | 62 | ... | 1.4796 | 1.4757 | 1.4720 | 118.9 | 118.7 | 0.3321 | 419.5 | .... |
| 0.8665* | 0.8535 | 0.8417 | 0.8272 | 0.8014 | 33.6 | 16.4 | 183 | 196 | 62 | ..... | 1.4794 | 1.4756 | 1.4717 | 119.0 | 118.7 | 0.3325 | 420.2 | .... |
| 0.8663* | 0.8530 | 0.8422 | 0.8268 | 0.8011 | 33.7 | 17.9 | 183 | 196 | 61 | .... | 1.4790 | 1.4751 | 1.4713 | 119.0 | 118.7 | 0.3324 | 420.4 | .... |
| 0.8697 | 0.8558 | 0.8439 | 0.8298 | 0.8038 | 33.2 | —26.7 | 176 | 189 | 62 | ..... | 1.4806 | 1.4767 | 1.4729 | 114.3 | 114.0 | 0.3323 | 402.7 | .... |
| 0.8464 | 0.8325 | 0.8214 | 0.8066 | 0.7818 | 37.8 | Glass | 175 | 189 | 60 | 1.4620 | 1.4614 | 1.4577 | 1.4539 | 115.5 | 115.5 | 0.3299 | 421.1 | 419.4 |

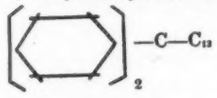
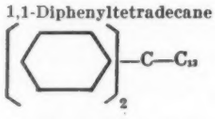
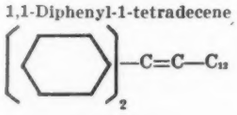
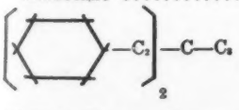
* Extrapolation values

**TABLE 2**

| PSC No. | Name of Structure | Empirical Formula | Kinematic Viscosity (Centistokes) 32 Deg F | 100 Deg F | 210 Deg F | Kinematic Viscosity Index (Dean and Davis) | Aniline Point Deg C | Deg F | Density (Grams Per Milliliter) 32 Deg F | Molecular Volume Extrapolated | Calculated | Refractive Index ($n^{20}_D$) Extrapolated | Calculated |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. | 11-*n*Butyldocosane | $C_{26}H_{54}$ | 46.39 | 10.41 | 2.78 | 124 | 113.8 | 236.8 | 0.8177 | 455.8 | 454.5 | 1.4500 | 1.4499 |
| 2. | 9-*n*Butyldocosane | $C_{26}H_{54}$ | 50.05* | 10.61 | 2.83 | 128 | 114.4 | 237.9 | 0.8176* | 456.0 | 454.5 | 1.4498 | 1.4492 |
| 3. | 7-*n*Butyldocosane | $C_{26}H_{54}$ | 50.29 | 11.10 | 2.93 | 131 | 114.2 | 237.6 | 0.8181 | 456.1 | 454.5 | 1.4499 | 1.4496 |
| 4. | 5-*n*Butyldocosane | $C_{26}H_{54}$ | 55.0* | 11.48 | 3.03 | 138 | 114.0 | 237.2 | 0.8192* | 455.1 | 454.5 | 1.4503 | 1.4501 |
| 5. | 7-*n*Hexyldocosane | $C_{28}H_{58}$ | 67.0* | 13.10 | 3.33 | 144 | 117.7 | 243.9 | 0.8208* | 488.6 | 487.0 | 1.4517 | 1.4514 |
| 6. | 9-*n*Octyldocosane | $C_{30}H_{62}$ | 73.0* | 14.43 | 3.56 | 148 | 116.9 | 242.4 | 0.8244* | 521.2 | 519.6 | 1.4537 | 1.4535 |
| 7. | 11-*n*Decyldocosane | $C_{32}H_{66}$ | 82.49 | 16.53 | 3.92 | 155 | 123.1 | 253.6 | 0.8254 | 554.2 | 552.2 | 1.4543 | 1.4544 |
| 8. | 11-*n*Decylheneicosane | $C_{31}H_{64}$ | 78.5* | 15.12 | 3.67 | 149 | 121.4 | 250.5 | 0.8243* | 538.3 | 535.9 | 1.4540 | 1.4537 |
| 62. | 11-*a*Decalinheneicosane | $C_{31}H_{60}$ | 457.54 | 45.67 | 6.36 | 95 | 108.9 | 228.0 | 0.8823 | 497.6 | 497.7 | 1.4778 | 1.4792 |
| 27. | 11-*n*Amylheneicosane | $C_{26}H_{54}$ | 45.02 | 10.08 | 2.73 | 125 | 114.1 | 237.4 | 0.8174 | 456.2 | 454.5 | 1.4497 | 1.4494 |
| 53. | 11-(3-Pentyl)-heneicosane | $C_{26}H_{54}$ | 47.83 | 10.39 | 2.75 | 119 | 113.4 | 236.1 | 0.8223 | 453.2 | 454.5 | 1.4517 | 1.4522 |
| 60. | 11-Cyclohexylheneicosane | $C_{27}H_{54}$ | 105.44 | 17.53 | 3.75 | 116 | 108.5 | 227.3 | 0.8499 | 452.3 | 452.0 | 1.4639 | 1.4648 |

* Solution freezes above aniline point.
* Extrapolation values.

**TABLE 2—Continued**

| PSC No. | Name of Structure | Empirical Formula | Kinematic Viscosity (Centistokes) 32 Deg F | 100 Deg F | 210 Deg F | Kinematic Viscosity Index (Dean and Davis) | Aniline Point Deg C | Deg F | Density (Grams Per Milliliter) 32 Deg F | Molecular Volume Extrapolated | Calculated | Refractive Index ($n^{20}D$) Extrapolated | Calculated |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 9. | 11-Phenylheneicosane<br>$C_{10}—C—C_{10}$<br> | $C_{27}H_{48}$ | 93.0* | 15.30 | 3.44 | 112 | 66.6 | 150.9 | 0.8659* | 436.9 | .... | 1.4788 | ..... |
| 52. | 11-Phenyl-10-heneicosene<br>$C_9—C=C—C_{10}$<br> | $C_{27}H_{46}$ | 69.74 | 12.51 | 3.06 | 115 | 48.2 | 118.8 | 0.8770 | 429.2 | .... | 1.4922 | ..... |
| 10. | 9-*p*Tolyloctadecane<br>$C_8—C—C_9$<br> <br>C | $C_{25}H_{44}$ | 90.19 | 14.75 | 3.15 | 75 | 63.3 | 145.9 | 0.8681 | 403.1 | .... | 1.4811 | ..... |
| 51. | 7-*n*Hexyleicosane<br>$C_6—C—C_{13}$<br>$C_6$ | $C_{26}H_{54}$ | 50.05* | 10.69 | 2.86 | 131 | 114.4 | 237.9 | 0.8170* | 456.1 | 454.5 | 1.4497 | 1.4496 |
| 11. | 1,1-Dicyclohexyltetradecane<br>  | $C_{26}H_{50}$ | 420* | 36.41 | 5.31 | 80 | 110.0 | 212.0 | 0.8857* | 415.7 | 416.9 | Solid | Solid |
| 12. | 1,1-Diphenyltetradecane<br>  | $C_{26}H_{38}$ | 141* | 18.59 | 3.72 | 92 | [a] | [a] | 0.9320* | 381.7 | .... | 1.5202 | ..... |
| 13. | 1,1-Diphenyl-1-tetradecene<br>  | $C_{26}H_{36}$ | 141* | 19.54 | 3.71 | 77 | [a] | [a] | 0.9406* | 376.2 | .... | 1.5363 | ..... |
| 25. | 9-*n*Octylheptadecane<br>$C_8—C—C_9$<br>$C_8$ | $C_{25}H_{52}$ | 37.90 | 8.93 | 2.49 | 116 | 11.6 | 232.9 | 0.8150 | 439.9 | 438.2 | 1.4487 | 1.4485 |
| 26. | 9-*n*Octyl-8-heptadecene<br>$C_7—C=C—C_9$<br>$C_8$ | $C_{25}H_{50}$ | 30.09 | 7.65 | 2.30 | 126 | 100.0 | 212.0 | 0.8223 | 433.8 | 433.7 | 1.4554 | ..... |
| 19. | 1-Cyclohexyl-3-(2-cyclohexylethyl)-hendecane<br>  | $C_{25}H_{48}$ | 332.38 | 33.49 | 4.98 | 70 | 98.4 | 209.1 | 0.8788 | 402.7 | 400.6 | 1.4756 | 1.4766 |

[a] Solution freezes above aniline point.
* Extrapolation values.

of their observations are not in agreement with our results, as will be shown later. In their study of oxidation characteristics of hydrocarbons, Larsen, Thorpe, and Armfield[7] prepared a number of hydrocarbons, some of which are in the range of our work.

### Compounds Prepared and Their Properties

Table 1 is a summarization of the 20 new hydrocarbons completed within the last year and their properties. As outlined in the first paper,[1] only those compounds are accepted and given PSC numbers that fulfill the following requirements: the purity shall be 95 mole percent, or better; more than 100 grams of material of this purity shall have been made; and a number of the significant physical properties must have been determined. Besides the constants tabulated, other physical properties are being determined or planned.

The densities and kinematic viscosities at 32° F., and the aniline points of the hydrocarbons covered at the last meeting,[1] have been determined and are listed in Table 2, as are the experimental and calculated molecular volumes. In the tables, notations such as $C_{10}$ refer to an unbranched, saturated chain of 10 carbon atoms, with their substituent hydrogens.

### Methods of Preparation

In general, the preparative procedures employed are the same as those described in the first paper[1] of this series. As stated therein, it is imperative that the reactions chosen are such that the number of byproducts is minimized. Further, the contaminants should be as different as possible in chemical properties and molecular weight from the desired material, thereby allowing very complete separation. Ease of manipulation and high yields are also desirable. To fulfill these requirements, we have found the Grignard preparation of alcohols, followed by dehydration and hydrogenation, to be the most satisfactory and the most generally applicable. Extensive research of the reactions of the Grignard reagent by organic chemists[3] permits rather accurate predictions of the reaction products. In addition, a variety of well-known reactions (Friedel-Crafts: aldol condensations, etc.) are employed in the preparation of intermediates.

Great care is exercised in the preparation and purification of the intermediates, for it is evident that the simplest means of minimizing isomeric impurities is to begin with pure starting materials. Whenever practicable, chemical methods of purification are employed first, with subsequent fractional distillation or crystallization, depending upon the substance. Fractionating columns, having efficiencies of 30 to 40 theoretical plates, are used for the purification of liquid intermediates.

From these pure starting materials, the hydrocarbons then are prepared. Both the olefins, from dehydration of the corresponding alcohols, and the final saturated hydrocarbons then are purified by fractionation and selective adsorption of impurities on silica gel. In order to fractionate these high-boiling liquids, a special column was built. Although of low efficiency (4 to 6 theoretical plates), the very low pressure drop permits distillation at pressures as low as 0.2 mm. Hence it is possible to fractionate hydrocarbons up to 35 carbon atoms per molecule without decomposition. Solvent extraction and fractional crystallization are being employed to a limited extent, primarily with the very high-molecular-weight compounds (more than 35 carbon atoms) and high-melting intermediates.

Detailed descriptions of the preparations of the individual hydrocarbons are being published as rapidly as possible in the appropriate journals.[4, 5]

* For a detailed treatment of the method, *cf.* B. J. Mair, A. R. Glasgow, Jr., and F. D. Rossini, *J. Research Natl. Bur. Standards* **26**, 591 (1941).

**TABLE 3**

**Fractionation of 11-(Cyclopentylmethyl)-heneicosane**

| FRACTION No. | $n^{20}D$ | Viscosity* (Efflux Time) |
|---|---|---|
| 4 | 1.4610 | 232.0 |
| 9 | 1.4611 | 234.3 |
| 13 | 1.4611 | 235.2 |

* Efflux time at 20° C, in seconds.

### Criteria of Purity

The methods and standards adopted for determination of purity of the final products have been outlined already.[1] One of the most reliable is thermodynamic analysis of the time-temperature melting curve, from which in most cases may be calculated rather accurately the mole percent purity.* Unfortunately, this method is of little value in the presence of stereoisomerism, changes in crystalline structure during melting, and formation of solid solutions and glasses. Considerable research by Project 42 led to the development of a relatively simple apparatus for the determination of time-temperature melting curves. Tests have shown the method to be accurate to ±0.3 mole percent. A typical curve is reproduced (Figure 1). A paper presenting details of construction and operation of the apparatus and a discussion of the method is complete, and will be published soon.

The secondary checks on purity in order of sensitivity and importance are:

a. Viscosity.
b. Refractive index.
c. Molecular refraction.

The research staff of Project 42 now is engaged in a study of the use of viscosity as a criterion of uniformity of composition. Our results show that, in every case studied thus far, viscosity is much more sensitive to small variations in composition than is refractive index (read to four places with an Abbe refractometer). With the Cannon-Fenske viscometer (ASTM D445-39T Method B) accurate measurements of kinematic viscosity are obtainable easily and rapidly. The values are reproducible to ±0.2 percent.[8]

As a typical example, 11-(cyclopentylmethyl)-heneicosane was prepared by hydrogenation of the olefins from the dehydration of 11-(cyclopentylmethyl)-11-heneicosanol. Fractionation of the hydrogenation product through the high vacuum column yielded the data shown in Table 3. Although there is no significant change in refractive index, the efflux time varies 3.2 seconds, or about 1.4 percent.

Rehydrogenation and fractionation gave the results listed in Table 4. Again there was no substantial change in refractive index, but a maximum viscosity variation of 1.5 seconds. However, this time most of the product (fractions 4 through 9) is of constant viscosity, indicating that the rehydrogenation has completed the saturation.

Viscosity as a criterion of uniformity of composition will be the subject of a separate paper.

The use of molecular refraction for proof of hydrocarbon type and structure is well known.[9, 10]

### Physical Constants

The physical properties of the hydrocarbons were determined as outlined in the first paper of this series.[1] *Boiling points* are accurate to ±0.5° C., and are reported at 0.50 and 1.00 mm. *Heats of vaporization* were

**TABLE 4**
**Fractionation of Rehydrogenated 11-(Cyclopentylmethyl)-heneicosane**

| FRACTION No. | $n^{20}D$ | Viscosity* (Efflux Time) |
|---|---|---|
| 2 | 1.4608 | 235.5 |
| 3 | 1.4609 | 235.8 |
| 4 | 1.4608 | 236.8 |
| 6 | 1.4609 | 237.0 |
| 9 | 1.4608 | 237.0 |
| 10 | 1.4609 | 236.6 |

* Efflux time at 20° C, in seconds.

calculated by use of the Clausius-Clapeyron equation from the vapor-pressure data for the range 0.50 mm. to 10.0 mm. The *aniline points* were determined as described in ASTM Method D611-41T, with a reproducibility of ±0.2° C. *Experimental molecular volumes* were obtained from the theoretical molecular weights and the densities at 20° C. The *calculated molecular volumes* for the saturated hydrocarbons are from the atomic values of Kurtz and Lipkin.[11]

The calculated values for the *refractive indices,* at 20° C., of the saturated hydrocarbons are from the equation proposed by Lipkin and Martin[18] involving temperature coefficient of density and density at 20° C. Whenever possible, *viscosities* and *densities* at 0° C. have been determined.

Consideration also is being given to the measurement of other physical properties.

### Influence of Structure on Physical Properties

An important aspect of research of this nature is its usefulness in drawing generalizations regarding the effect of structure on physical properties. For this major purpose, Project 42 is studying in detail several types of hydrocarbons in the range of 25 to 60 carbon atoms. The compounds investigated in the past year and herein reported consist mainly of long-chain hydrocarbons with one or two cyclic substituents. Whenever pertinent, the data tabulated in the first paper[1] have been used in the comparisons.

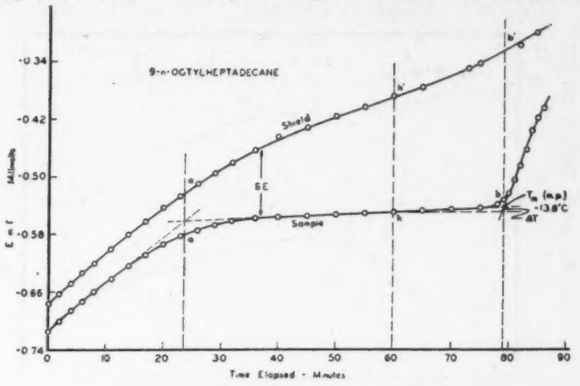



**FIGURE 1**
**Sample Time-Temperature Melting Curve**

Generalizations based on insufficient data are dangerous, and we emphasize that those proposed in this paper are tentative, pending further work in this field.

Hugel[12] assumed that branching in the *iso*paraffins had little effect on viscosity. We have shown[1] that, although variation of position and branching—molecular

**TABLE 5**
**Effect of Multiple Branching**

| PSC No. | Name<br>Structure | Melting Point (Deg C) | —$C_{26}H_{54}$ *Iso*paraffins— Viscosity (Centistokes at 100 deg F) | Kinematic Viscosity Index | Boiling Point at 1.00 Mm (Deg C) | $n^{20}D$ | $d^{20}$ | Aniline Point (Deg C) |
|---|---|---|---|---|---|---|---|---|
| 4.* | 5-*n*Butyldocosane<br>$C_4—C(—C_{17})—C_4$ | 20.8 | 11.48 | 138 | 195 | 1.4503 | 0.8057 | 114.0 |
| 55. | 5,14-di-*n*Butyloctadecane<br>$C_4—C(—C_8—C(—C_4)—C_4)—C_4$ | 5.7 | 12.18 | 84 | 185 | 1.4508 | 0.8075 | 111.3 |
| 27.* | 11-*n*Amylheneicosane<br>$C_{10}—C(—C_{10})—C_5$ | — 9.1 | 10.08 | 125 | 192 | 1.4497 | 0.8038 | 114.1 |
| 22. | 6,11-di-*n*Amylhexadecane<br>$C_5—C(—C_4—C(—C_5)—C_5)—C_5$ | —16.2 | 11.80 | 72 | 182 | 1.4502 | 0.8068 | 112.0 |
| 51.* | 7-*n*Hexyleicosane<br>$C_6—C(—C_{13})—C_6$ | 10.2 | 10.69 | 131 | 194 | 1.4497 | 0.8040 | 114.4 |
| 23. | 3-Ethyl-5-(2-ethylbutyl)-octadecane<br>$C_2—C(—C—C(—C_{13})—C(—C_2)—C(—C_2)—C_2)—C_2$ | Glass | 11.84 | 102 | 180 | 1.4521 | 0.8109 | 112.1 |

* For other properties, *cf.* I.[1]

weight being constant—has relatively little effect on refractive index and density, it has a marked effect on viscosity, viscosity index, and boiling point. The changes brought about by multiple branching are even more pronounced. Invariably the viscosity has been in-

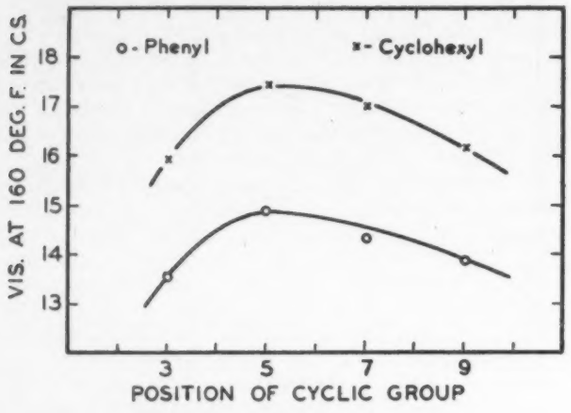



**FIGURE 2**
**Change of Kinematic Viscosity with Position of Cyclic Group**

creased slightly and the viscosity index decreased greatly by this "clustering" of the hydrocarbon molecule. The viscosity indices of the polybranched *iso*paraffins listed in Table 5 are in the same range as those of the dicyclic aromatics and naphthenics of similar molecular weight. The transition from the *n*hexyl groups of PSC 51 to the 2-ethylbutyl groups of PSC 23 resulted in a viscosity increase (at 100° F.) of about 11 percent, with a 22-percent decrease in kinematic viscosity index. The viscosity index of PSC 55 is less than two thirds that of PSC 4.

The tentative conclusion stated in the first paper,[1] i.e., that increasing the length of side chain and decreasing that of the main carbon chain (without change of position) tends to lower viscosity, is borne out by comparison of PSC compounds 55,22. However, length of straight chain is not the only determining factor, for PSC compounds 55 and 23 both have 18 carbon chains, yet differ by 0.34 centistokes in viscosity (at 100° F.) and by 18 in viscosity index.

Clustering of the molecule through multiple branching further is characterized by decreased boiling point (10° C. or more at 1.00 mm in the examples listed), decreased aniline point, and increased refractive index and density. Inasmuch as *iso*paraffins generally are assumed to have high viscosity indices, the extraordinarily low values for PSC compounds 22 and 55 are especially interesting to the petroleum chemist. Evi-

**TABLE 6**
**Effect of Position of Cyclic Group**

| PSC No. | Substituted Eicosane* | Melting Point (° C) | $C_{20}H_{54}$ Hydrocarbons: Viscosity (Centistokes at 100° F) | Kinematic Viscosity Index | Boiling Point at 1.0 Mm (° C) | $n^{20}D$ | $d^{20}$ | Aniline Point (° C) |
|---|---|---|---|---|---|---|---|---|
| 79 | 3-Phenyl- | 29.3 | 13.54 | 143 | 202 | 1.4796 | 0.8546† | 61.3 |
| 80 | 5-Phenyl- | 30.2 | 14.89 | 112 | 197 | 1.4796 | 0.8548† | 61.4 |
| 81 | 7-Phenyl- | 16.4 | 14.35 | 108 | 196 | 1.4794 | 0.8535 | 62.2 |
| 82 | 9-Phenyl- | 17.9 | 13.90 | 105 | 196 | 1.4790 | 0.8530 | 63.4 |
| 75 | 3-Cyclohexyl- | 22.7 | 15.96 | 156 | 205 | 1.4642 | 0.8383 | 107.7 |
| 76 | 5-Cyclohexyl- | —2.2 | 17.44 | 119 | 202 | 1.4638 | 0.8371 | 107.0 |
| 77 | 7-Cyclohexyl- | Glass | 17.00 | 111 | 200 | 1.4635 | 0.8367 | 106.7 |
| 78 | 9-Cyclohexyl- | Glass | 16.19 | 107 | 199 | 1.4635 | 0.8368 | 106.4 |

* *Cf.* Table 1 for structures and other properties.
† Extrapolation values.

dently increased branching of the hydrocarbon molecule results in a much steeper slope for the viscosity-temperature curve.

**Influence of Position of Cyclic Group (Cf. Table 6)**

The effect on physical properties of the position of branch in the *iso*paraffins was shown with the *n*butyldocosanes in the first paper.[1] We now have partly completed a series in which a phenyl or cyclohexyl group is moved along a 20-carbon straight chain; and for both types of rings the same general trends are to be observed, differing only in that the changes are somewhat greater for the cyclohexyl.

As the ring is moved from the center toward the end of the paraffinic chain, the kinematic viscosity index rapidly *increases*, whereas viscosity passes through a *maximum* when the substituent group is in position **5** (Table 6; Figures 2 and 3). The derivatives with the rings in position **4** have been synthesized, but insufficient data prevent their inclusion in this paper. It may be stated, however, that their viscosities and viscosity indices fall on the smooth curves in Figures 2 and 3. The compounds with the cyclic groups in positions **1** and **2** are being prepared in order to check these conclusions. These findings concerning viscosity and viscosity index are in agreement with the

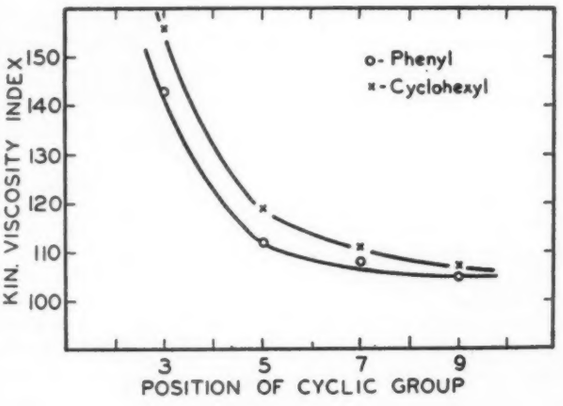



**FIGURE 3**
**Variation of Kinematic Viscosity Index with Position of Cyclic Group**

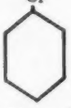
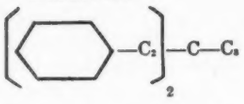
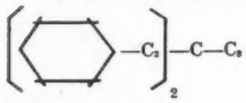
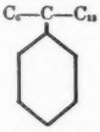
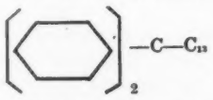
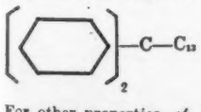
data listed by Mikeska[2] for his pairs of compounds 2,3; 32,33; 38,39. However, they do not agree with his tentative conclusion that location of the nucleus within the molecule has a small effect on the viscosity index of the oil.

It will be noted that in this series the boiling points at 1.00 mm vary in the same direction as the viscosity indices. That this is not the general rule will be shown later. As illustrated in Figure 4, the trend in aniline point for the phenyl derivatives is, rather surprisingly, just the reverse of that for the cyclohexyl compounds. Although the differences are not large, inasmuch as most of them are greater than the experimental error, it must be concluded that the direction of variation is correct.

The variations in density are small but similar to those noted for the viscosity index and boiling point: density increases as the substituent cyclic nucleus is moved nearer the end of the normal 20-C chain. This increase in density tends to increase refractive index.

Completion of the 1-,2-, and 4-phenyl and cyclohexyl derivatives, as well as several corresponding naph-

**TABLE 7**
**Effect of Cyclization**

| PSC No. | Name<br>Structure | Melting Point (Deg C) | Viscosity (Centistokes at 100 Deg F) | Kinematic Viscosity Index | Boiling Point at 1.00 Mm (Deg C) | $n^{20}D$ | $d^{20}$ | Aniline Point (Deg C) |
|---|---|---|---|---|---|---|---|---|
| 26.* | 9-*n*Octyl-8-heptadecene ..... | Glass | 7.65 | 126 | 181 | 1.4554 | 0.8084 | 100.0 |
| | $C_8—C=C.\underset{\displaystyle C_8}{\overset{\displaystyle C_8}{\overset{|}{C}}}—C_8$ | | | | | | | |
| 25.* | 9-*n*Octylheptadecane ..... | —13.8 | 8.93 | 116 | 184 | 1.4487 | 0.8017 | 111.6 |
| | $C_8—\underset{\displaystyle C_8}{\overset{\displaystyle C_8}{\overset{|}{C}}}—C_8$ | | | | | | | |
| 87. | 9-(2-Phenylethyl)-heptadecane .. | —26.7 | 9.38 | 108 | 189 | 1.4806 | 0.8558 | 53.1 |
| | $C_8—\underset{\displaystyle C_2}{\overset{\displaystyle C_8}{\overset{|}{C}}}—C_8$  | | | | | | | |
| 18. | 1-Phenyl-3-(2-phenylethyl)-hendecane | Fluid below —60 | 12.61 | 78 | 197 | 1.5192 | 0.9211 | † |
| |  | | | | | | | |
| 88. | 9-(2-Cyclohexylethyl)-heptadecane | Glass | 14.72 | 101 | 189 | 1.4614 | 0.8325 | 104.8 |
| | $C_8—\underset{\displaystyle C_2}{\overset{\displaystyle C_8}{\overset{|}{C}}}—C_8$ | | | | | | | |
| 19.* | 1-Cyclohexyl-3-(2-cyclohexylethyl)-hendecane | Glass | 33.49 | 70 | 195 | 1.4756 | 0.8657 | 98.4 |
| |  | | | | | | | |
| 51.* | 7-*n*Hexyleicosane ..... | 10.2 | 10.69 | 131 | 194 | 1.4497 | 0.8040 | 114.4 |
| | $C_6—\underset{\displaystyle C_6}{\overset{\displaystyle C_{13}}{\overset{|}{C}}}$ | | | | | | | |
| 81. | 7-Phenyleicosane ..... | 16.4 | 14.35 | 108 | 196 | 1.4794 | 0.8535 | 62.2 |
| | $C_6—\underset{}{\overset{\displaystyle C_{13}}{\overset{|}{C}}}$  | | | | | | | |
| 12.* | 1,1-Diphenyltetradecane ..... | 17.9 | 18.59 | 92 | 207 | 1.5202 | 0.9186 | † |
| |  | | | | | | | |
| 77. | 7-Cyclohexyleicosane ..... | Glass | 17.00 | 111 | 200 | 1.4635 | 0.8367 | 106.7 |
| | $C_6—\underset{}{\overset{\displaystyle C_{13}}{\overset{|}{C}}}$ | | | | | | | |
| 11.* | 1,1-Dicyclohexyltetradecane .... | 37.6 | 36.41 | 80 | 206 | Solid | 0.8726 | 100.0 |
| |  | | | | | | | |

* For other properties, *cf.* I.[1]
† Solution solidifies before separation into two liquid phases.

thyleicosanes, should serve as an interesting check on the accuracy of these tentative conclusions.

### Effect of Progressive Cyclization of the Hydrocarbon Molecule

The enormous influence of cylization on physical properties already has been noted by Hugel[15] and other workers.[2, 13] The former concluded that cyclization greatly increased viscosity, and that hydroaromatics have a higher viscosity than the corresponding aromatics. In his extensive work on the chemical structure of lubricating oil, Mikeska[2] observed that the viscosity index is increased by an increase in the ratio of paraffinic to naphthenic or aromatic carbon atoms. However, in each of the comparative cases from which this conclusion was drawn, one or both of the following complicating variables entered in: increase in molecular weight and change of ring type (fused or non-fused).

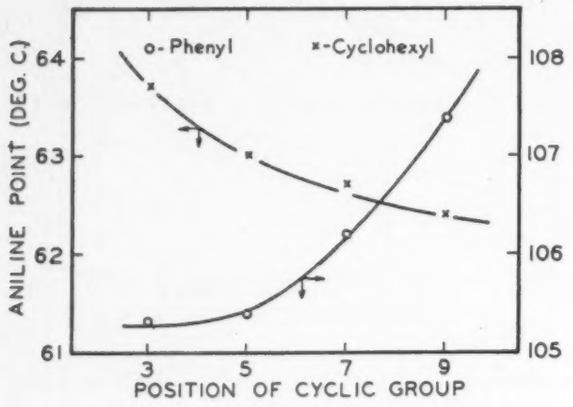



**FIGURE 4**
**Variation of Aniline Point with Position of Cyclic Group**

In the two series of hydrocarbons (Table 7) prepared by us for study of the effect of cyclization, the molecular weight has been maintained practically constant and the basic skeletal symmetry of the molecules preserved. It will be noted the two series differ from each other in carbon content, the first being 25-carbon and the second 26-carbon. Two other members of the 25-carbon "2-phenylethyl" series are in preparation—one containing three 2-phenylethyl groups, and the other three 2-cyclohexylethyl groups.

Examination of the data in Table 7 discloses the following qualitative facts:

1. Invariably, viscosity is increased through cyclization. Progressive ring formation also results in increased boiling point, density, and refractive index; the aniline point consistently is decreased. In agreement with the conclusion of Mikeska,[2] cyclization decreases viscosity index.

2. Viscosity is increased much more greatly by cyclization to non-fused hydroaromatic rings than to aromatic ones. For the examples shown, one naphthenic nucleus is roughly equivalent to two aromatic rings, other things being equal. Further, the viscosity indices of the monocyclic naphthenes are higher than those of the similar dicyclic aromatics.

3. Progression from *iso*paraffin to monoaromatic to diaromatic (non-fused) has a much smaller effect on viscosity than the comparable transition involving hydroaromatics. For the same changes, the drop in viscosity index is not greatly different. Moreover, the effect on viscosity of the second substituent naphthenic group is remarkably greater than that brought about by the shift from *iso*paraffin to mononaphthene. Compare PSC compounds 25,88,19 and 51,77,11. Going from 25 to 88 the viscosity increases about 6 centistokes (similarly from 51 to 77); whereas from 88 to 19 the change in viscosity is about 19 centistokes (also from 77 to 11). This enormous viscosity increase and the great similarity between the two series, insofar as the cyclohexyl derivatives are concerned, are illustrated in Figure 5. The curves showing viscosity vs. percent carbon atoms in rings for the cyclohexyl derivatives of the two series follow each other regularly.

The 25-C series should prove even more interesting on completion of the compounds containing three cyclic groups per molecule. A similar series containing cyclopentyl rings in the place of the cyclohexyls is planned.

### Comparison of the Relative Effects of Cyclopentyl, Cyclohexyl, and Phenyl Groups

Changing from a cyclohexyl to cyclopentyl group produces interesting changes in physical properties. Comparison of the compounds listed in Table 8 shows that the monocyclic cyclopentyl derivative is considerably less viscuous (at 100° F.) than either the corresponding aromatic or hydroaromatic derivative. Although the cyclopentyl hydrocarbon has only 26 carbon atoms as compared to the 27 carbon atoms of PSC compounds 9 and 60, former work[1] has shown that an additional methylene group increases the viscosity at 100° F. by only 1.0 to 1.5 centistokes. Therefore, if PSC 64 were a 27-carbon-atom hydrocarbon of similar structure, at most its viscosity at 100° F. would be approximately 14.0 centistokes.

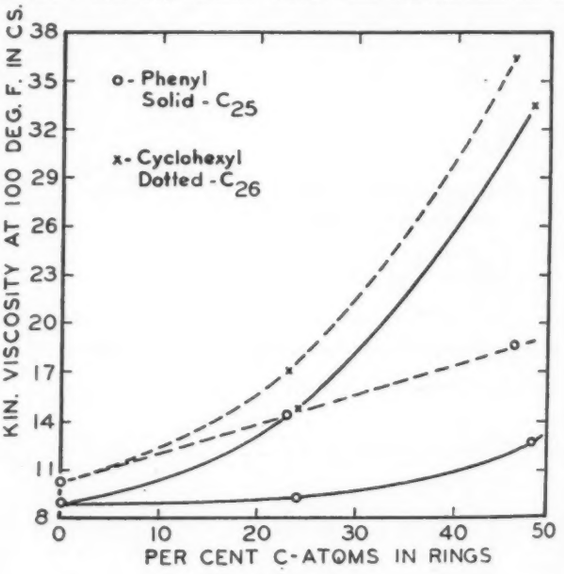



**FIGURE 5**
**Variation of Kinematic Viscosity with Cyclization**

Further, the viscosity index of the cyclopentyl de-

**TABLE 8**
**Similar Cyclopentyl, Phenyl, and Cyclohexyl Compounds**

| PSC No. | Substituted Heneicosanes | Melting Point (° C) | Viscosity (Centistokes at 100 (° F) | Kinematic Viscosity Index | Boiling Point at 1.00 Mm (° C) | $n^{20}_D$ | $d^{20}$ | Aniline Point (° C) |
|---|---|---|---|---|---|---|---|---|
| 64..... | 11-Cyclopentyl- | —12.7 | 12.53 | 122 | 199 | 1.4613 | 0.8329 | 106.5 |
| 9*..... | 11-Phenyl- | 20.8 | 15.30 | 112 | 205 | 1.4788 | 0.8531 | 66.6 |
| 60*..... | 11-Cyclohexyl- | — 7.2 | 17.53 | 116 | 209 | 1.4639 | 0.8373 | 108.5 |

* For structures and other properties, *cf*, I.[1]

rivative is greater than that of either the phenyl or cyclohexyl. Preliminary results on a 27-carbon-atom compound similar to PSC 64 reveal that an additional methylene group will increase the viscosity index; thus the difference should be even greater than is shown by Table 8.

Many more cyclopentyl hydrocarbons, both mono- and polycyclic, must be studied before great significance can be placed in these results and before basic generalizations may be drawn. The research staff of Project 42 has begun considerable work in this field.

The results of a study of the effect of structure on physical properties are tabulated in Table 9. This series was prepared to establish the relations between the various types of paraffinic groups and the corresponding cyclopentyl derivative.

As formerly observed (Table 5), clustering of the hydrocarbon molecule through increased branching results in an increase in viscosity at 100° F. and a decrease in viscosity index. This fact is illustrated further by comparison of PSC compounds 27,53 and 67, listed in Table 9. As might be predicted, the cyclopentyl compound corresponding to these derivatives of heneicosane has the highest viscosity of the series. However, the viscosity increase through cyclization is much less than that noted when a hydroaromatic ring is formed (*cf.* Table 7), which might have been foreseen by a comparative study of the relative viscosities listed in Tables 7 and 8.

The difference in the viscosity indices of the monobranched *iso*paraffin PSC 27 and the cyclopentyl PSC 64 is remarkably small compared to the variation found for the change from *iso*paraffin to monohydroaromatic (Table 7). Cyclization again caused a marked increase in boiling point, density, and refractive index, and a decrease in aniline point.

The decrease in density from the *n*amyl (PCS 27) to the neopentyl (PSC 67) is in keeping with the relative densities of *n*pentane and neopentan.

## Properties of Mixtures

Project 42 has begun an investigation of the properties of mixtures of the pure compounds now available. The work on three different binary systems is partly complete, and is very interesting. Because of the preliminary nature of the research, no generalizations are attempted.

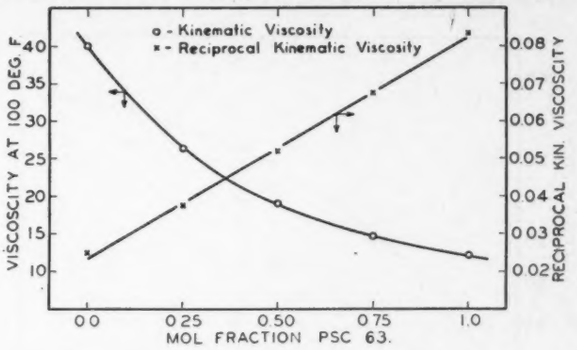



**FIGURE 6**
**Viscosity-Composition Curves—Mixtures No. 63/65**

The viscosities and densities of the mixtures were determined as has been described for the pure compounds.[1]

Unfortunately pour-point data on the mixtures cannot be reported at this time due to experimental difficulties. However, it may be stated that the mixing of these pure compounds causes considerable lowering of the pour point.

## Mixtures No. 63/65

*Mixed Molecular Type; Different Viscosities and Viscosity Indices*

Mixtures No. 63/65 is a binary system composed of the *iso*paraffinic 9-*n*octyleicosane (PSC 63) and the

**TABLE 9**
**Various 11-$C_5$-Heneicosanes**

| PSC No. | Substituted Heneicosane and Structure | Melting Point (Deg C) | Viscosity (Centistokes at 100 Deg F) | Kinematic Viscosity Index | Boiling Point at 1.00 Mm (Deg C) | $n^{20}D$ | $d^{20}$ | Aniline Point (Deg C) |
|---|---|---|---|---|---|---|---|---|
| 27.* | 11-*n*Amyl | — 9.1 | 10.08 | 125 | 192 | 1.4497 | 0.8038 | 114.1 |
| 53.* | 11-(3-Pentyl) | Glass | 10.39 | 119 | 188 | 1.4517 | 0.8092 | 113.4 |
| 67. | 11-Neopentyl | —21.0 | 11.71 | 106 | 189 | 1.4491 | 0.8029 | 114.9 |
| 64. | 11-Cyclopentyl | —12.7 | 12.53 | 122 | 199 | 1.4613 | 0.8329 | 106.5 |

* For other properties, *cf.* I.[1]

naphthenic 1-cyclohexyl-2-(cyclohexylmethyl)-pentadecane (PSC 65), both of which are 28-carbon-compounds. For structures, see Table 1.

The variation of both the kinematic viscosity and the reciprocal of the kinematic viscosity with composition is graphically shown in Figure 6. The curvature of the

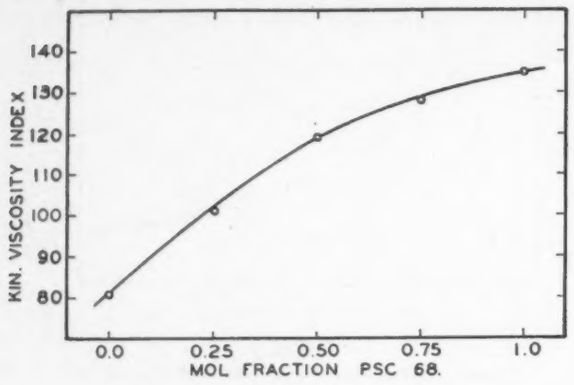



**FIGURE 7**
**Kinematic-Viscosity-Index-Vs.-Composition Curve**

viscosity-composition curve indicates that in this binary system the lower viscosity constituent (PSC 63) exerts the greater influence in determining the viscosity of the mixture. For this series of mixtures, the reciprocal of the kinematic viscosity varies almost directly with the composition. The viscosity-index-composition curve (Figure 7) is concave downward, and the viscosities at 100 and 210° F. vary similarly.

As would be expected, the densities of the mixtures are linear functions of the composition.

## Mixtures No. 67/78

*Mixed Molecular Type; Equal Viscosity Indices and Similar Viscosities*

Binary system No. 67/78 has as components the *iso*paraffinic 11-neopentylheneicosane (PSC 67) and naphthenic 9-cyclohexyleicosane (PSC 78), 26-carbon hydrocarbons whose structural formulas are given in Table 1. The physical properties of the mixtures and the pure compounds are summarized in Table 11. For

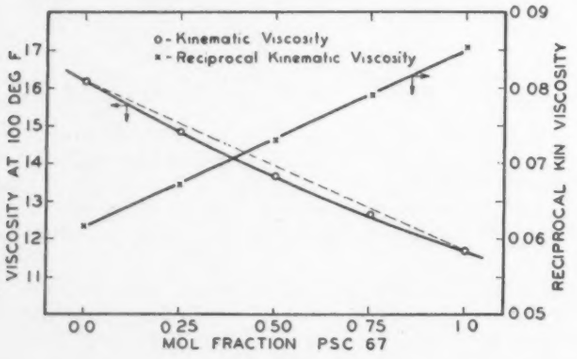



**FIGURE 8**
**Viscosity-Composition Curves—Mixtures No. 67/78**

structures of the hydrocarbons and their other physical properties, the reader is referred to Table 1.

Although the curve for the viscosity (at 100° F.)-mole fraction (Figure 8) varies only slightly from a straight line (shown as a dotted line to accentuate the curvature), the difference is greater than the possible experimental error. As noted in the case of mixtures No. 63/65, it appears that the lower-viscosity substance (11-neopentylheneicosane; PSC 67) exerts a slightly greater influence on the kinematic viscosity. Here also the relation between the reciprocal kinematic viscosity and composition is practically linear (Figure 8).

**TABLE 10**
**Mixtures No. 63/65**

| Mole Fraction PSC 63 | Viscosity, Centistokes at ° F: 32 | 68 | 100 | 210 | Density, Grams Per Milliliter at ° F: 68 | 100 | 210 | Kinematic Viscosity Index |
|---|---|---|---|---|---|---|---|---|
| 1.00 | 60.2* | 22.39 | 12.03 | 3.10 | 0.8074 | 0.7959 | 0.7564 | 135 |
| 0.75 | 77.98 | 29.25 | 14.86 | 3.48 | 0.8213 | 0.8093 | 0.7703 | 128 |
| 0.50 | 120.7 | 40.57 | 19.26 | 3.99 | 0.8353 | 0.8230 | 0.7842 | 119 |
| 0.25 | 213.6 | 61.73 | 26.63 | 4.67 | 0.8492 | 0.8372 | 0.7988 | 101 |
| 0.00 | 500* | 107.0 | 40.27 | 5.63 | 0.8632 | 0.8518 | 0.8135 | 81 |

* Extrapolation values.

The Viscosity indices of the pure components are substantially equal, and mixing has little or no effect on the viscosity index for these mixtures (Figure 9). As found for all of the mixtures studied by Project 42, the relationship between the density and composition is linear.

## Mixtures No. 22/3

*Same Molecular Type; Similar Viscosities; Different Viscosity Indices*

The binary system No. 22/3 is composed of two 26-carbon *iso*paraffins having nearly equal viscosities but widely varying viscosity indices. The components

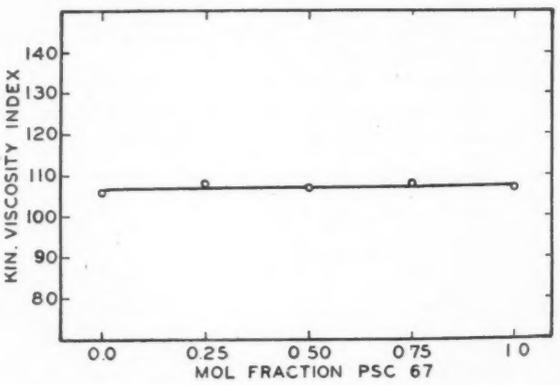



**FIGURE 9**
**Kinematic-Viscosity-Index-Vs.-Composition Curve**

of these mixtures are 6,11-di-*n*amylhexadecane (PSC 22) and 7-*n*butyldocosane (PSC 3). For the structures and other properties of the constituent hydrocarbons, see Table 1 and I.[1]

Over the very short viscosity interval for these hydrocarbons, the variation of viscosity with composition is practically linear, as illustrated in Figure 10. Further-

**TABLE 11**
**Mixtures No. 67/68**

| Mole Fraction PSC 27 | Viscosity, Centistokes at ° F: 32 | 68 | 100 | 210 | Density, Grams per Milliliter at ° F: 68 | 100 | 210 | Kinematic Viscosity Index |
|---|---|---|---|---|---|---|---|---|
| 1.00 | 60.07 | 22.64 | 11.71 | 2.89 | 0.8029 | 0.7915 | 0.7525 | 106 |
| 0.75 | 67.06 | 24.76 | 12.66 | 3.04 | 0.8121 | 0.8004 | 0.7608 | 108 |
| 0.50 | 75.07 | 27.22 | 13.69 | 3.18 | 0.8204 | 0.8092 | 0.7692 | 107 |
| 0.25 | 84.45 | 29.98 | 14.85 | 3.35 | 0.8290 | 0.8168 | 0.7778 | 108 |
| 0.00 | 95.02 | 33.34 | 16.19 | 3.52 | 0.8368 | 0.8254 | 0.7863 | 107 |

more, although the pure components differ radically in viscosity index, the graph of the viscosity indices of the mixture vs. composition gives a fairly acceptable straight line, the error being approximately ±4 (Figure 10). Thus for both binary systems No. 67/78 and No. 22/3, where the viscosities of the pure components

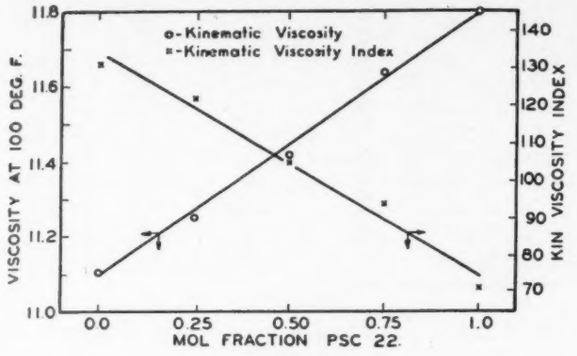



**FIGURE 10**
**Viscosity and Kinematic-Viscosity-Index Curves—Mixtures No. 22/3**

are not radically different, the change of viscosity index with composition is substantially linear.

Within experimental error, the variation of density with composition is linear for this series of mixtures.

Much more research in this field is necessary before these results can be correlated completely.

## Carbon Atoms in Naphthenic Rings

Davis and McAllister[14] have proposed the following formula for calculating the number of carbon atoms per molecule in naphthenic rings:

N=(0.358) (molecular weight)—7.7—(0.3) (molecular volume)

*where: N*=number of carbon atoms in naphthenic rings. Neyman-Pilat and Pilat[6] reported the method to be accurate for the seven mono- and dicyclic hydrocarbons studied by them.

As shown in Table 13, the agreement between the theoretical and calculated values for our hydrocarbons is good for the non-condensed dicyclic naphthenes (PSC compounds 11, 19, 65), and fair for the monocyclic naphthenes (PSC compounds 60, 64, 69, 76). However, the method gives values considerably above zero for the *iso*paraffins (PSC compounds 1, 22, 23, 55, 63, 67). The deviation appears to increase for the *iso*paraffins with increased branching, but is somewhat erratic. That the discrepancies noted for the pure compounds extend into the mixtures of these hydrocarbons is shown also in Table 13. It is evident that, for this molecular-weight range, the method gives high values when the number of carbon atoms in naphthenic rings is less than 12. Use of a correction graph, such as Figure 16, is suggested for this molecular-weight range. Values calculated from the formula of Davis and McAllister,[14] when corrected with the aid of this chart, have an average deviation of ±0.6 from the theoretical number of carbon atoms in naphthenic rings.

**TABLE 12**
**Mixtures No. 22/3**

| Mole Fraction PSC 22 | Viscosity, Centistokes at ° F: 32 | 68 | 100 | 210 | Density, Grams per Milliliter at ° F: 68 | 100 | 210 | Kinematic Viscosity Index |
|---|---|---|---|---|---|---|---|---|
| 1.00 | 65.50 | 23.78 | 11.80 | 2.74 | 0.8068 | 0.7952 | 0.7549 | 72 |
| 0.75 | 60.73 | 22.70 | 11.64 | 2.82 | 0.8061 | 0.7946 | 0.7542 | 94 |
| 0.50 | 56.80 | 21.84 | 11.42 | 2.84 | 0.8057 | 0.7938 | 0.7537 | 105 |
| 0.25 | 53.29 | 21.12 | 11.25 | 2.90 | 0.8050 | 0.7933 | 0.7536 | 122 |
| 0.00 | 50.29 | 20.50 | 11.10 | 2.93 | 0.8040 | 0.7926 | 0.7522 | 131 |

**TABLE 13**
**Carbon Atoms in Naphthenic Rings**

| PSC No. | Molecular Weight | Experimental Molecular Volume | Carbon Atoms in Naphthenic Rings: Theoretical | Davis and McAllister[14] |
|---|---|---|---|---|
| 1 | 367 | 456 | 0 | 2.3 |
| 22 | 367 | 454 | 0 | 2.9 |
| 23 | 367 | 452 | 0 | 3.5 |
| 55 | 367 | 454 | 0 | 2.9 |
| 63 | 395 | 489 | 0 | 2.4 |
| 67 | 367 | 457 | 0 | 2.0 |
| 60 | 379 | 452 | 6 | 7.8 |
| 64 | 365 | 438 | 5 | 7.0 |
| 69 | 435 | 518 | 6 | 8.0 |
| 76 | 365 | 436 | 6 | 7.6 |
| 11 | 362 | 416 | 12 | 12.5 |
| 19 | 349 | 403 | 12 | 11.7 |
| 62 | 433 | 498 | 10 | 13.2 |
| 65 | 391 | 453 | 12 | 11.8 |
| Mole Fraction PSC 63 | MIXTURES NO 63/65 | | | |
| 0.75 | 394 | 480 | 3 | 4.8 |
| 0.50 | 393 | 470 | 6 | 7.4 |
| 0.25 | 392 | 462 | 9 | 9.4 |
| Mole Fraction PSC 67 | MIXTURES NO. 67/78 | | | |
| 0.75 | 367 | 452 | 1.5 | 3.5 |
| 0.50 | 366 | 446 | 3 | 4.9 |
| 0.25 | 365 | 440 | 4.5 | 6.4 |

## Percent by Weight of Aromatic Rings by Waterman[16]

*Method of Analysis*

A procedure for the calculation of weight percent aromatic rings has been suggested by Vlugter, Waterman, and van Westen.[16] It is dependent on the change in aniline point on hydrogenation, and is based on the assumption of a smooth-curve relationship between aniline point and molecular weight. For only four of the hydrocarbons prepared by Project 42 containing aromatic rings was it possible to obtain aniline points for in two cases the aniline-polyaromatic hydrocarbon mixtures solidified before the aniline point was reached.

In Table 14 are listed both the theoretical and calculated percentages of aromatic rings.

These results illustrate the inadequacy of the method

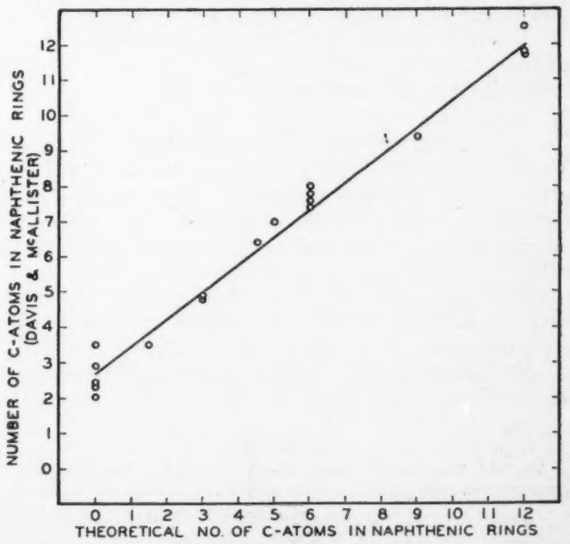



**FIGURE 11**
**Theoretical Vs. Calculated[14] Number of Carbon Atoms in Naphthenic Rings**

as applied to these pure hydrocarbons. In each case the calculated value is much too high. This conclusion is given added weight by the similar findings of Neyman-Pilat and Pilat.[6]

The Vlugter, Waterman, and van Westen[16] calcula-

**TABLE 14**
**Weight Percent of Aromatic Rings**

| PSC No. | Change in Aniline Point on Hydrogenation (° C) | Molecular Weight | Weight Percent Aromatic Rings | |
|---|---|---|---|---|
| | | | Theoretical | Waterman[16] |
| 68 | 36.1 | 428 | 18.0 | 30.7 |
| 80 | 45.6 | 358 | 21.5 | 38.8 |
| 87 | 51.7 | 344 | 22.4 | 43.9 |
| 9 | 41.9 | 372 | 20.7 | 35.6 |

tion of the weight-percentage aromatic rings is made by multiplying the difference in aniline point caused by hydrogenation by the factor 0.85. Thus:

(Aniline point naphthene—aniline point aromatic) (factor)=weight percent of aromatic rings.

For our compounds, those of Neyman-Pilat and Pilat,[6] and the suitable hydrocarbon pairs of Mikeska,[2] a good approximation is achieved if the factor is changed to 0.47, as shown in Table 15.

The molecular weights of these compounds range from 2994 to 436, and the hydrocarbons are mono- and dicyclic (both condensed and non-condensed) in type.

## Variation of Aniline Point with Carbon Content

Mair, Willingham, and Streiff[17] gave a series of curves showing the relation between the aniline points of various types of hydrocarbons and the number of carbon atoms per molecule.

A comparison of the experimental aniline points of our hydrocarbons with those obtained from the above-mentioned curves is shown in Table 16.

In general, agreement is rather good for all types of compounds except the aromatics ($x$: —6). The most important criticism to be advanced is that in almost every case the values from the curves[17] are high. However, in view of the fact that the curves were plotted using a relatively few points, the values for the saturated hydrocarbons correspond reasonably well.

## Conclusions

Following is a summarization of the results reported in this paper and in I.[1] The generalizations are all tentative, based on our researches and those of other workers, whenever possible.

### Viscosity and Viscosity Index

1. In general, both viscosity and viscosity index are increased by increasing molecular weight, basic molecular symmetry remaining constant.

2. For every compound studied by Project 42, increased branching of the molecule has been accompanied by an increase in viscosity (at 100° F.) and a marked lowering of the viscosity index (45 percent, in one example).

3. Each step of the transition from *iso*paraffin to aromatic to hydroaromatic generally results in a marked increase in viscosity and a decrease in kinematic viscosity index.

4. Position of cyclic group (aromatic or hydroaromatic) on a paraffinic chain has a definite effect on viscosity. Viscosity index may increase as much as 45 percent on shifting the ring from the center to near the end of a paraffinic carbon chain.

Surprisingly enough, not one of the 8 mononuclear naphthenes thus far studied by us has a viscosity index below 100, and only one of the 8 monocyclic aromatic hydrocarbons is below that figure. Moreover, 2 of the 16 *iso*paraffins, and *all* 4 of the dicyclic naphthenes, have viscosity indices of less than 100.

Davis and McAllister[14] have suggested plotting kinematic viscosity index vs. percentage of carbon atoms in naphthenic rings. That the method is inadequate for pure hydrocarbons is shown in Figure 12.

**TABLE 15**
**Weight Percent Aromatic Rings Employing New Factor**

| Compound No. | Change in Aniline Point on Hydrogenation (° C) | Weight Percent Aromatic Rings | |
|---|---|---|---|
| | | Theoretical | This Work |
| 68 | 36.1 | 18.0 | 17.0 |
| 80 | 45.6 | 21.5 | 21.4 |
| 87 | 51.7 | 22.4 | 24.3 |
| 9 | 41.9 | 20.7 | 19.7 |
| 2* | 51.4 | 25 | 24.2 |
| 6* | 105.9 | 51 | 49.8 |
| 3† | 46.0 | 19.9 | 21.6 |
| 17† | 65.5 | 31.4 | 30.8 |

* Hydrocarbons No. 2 and 6 of Neyman-Pilat and Pilat.[6]
† Hydrocarbons No. 3 and 17 of Mikesha.[2]

**TABLE 16**
**Aniline Point—Experimental and Calculated**

| PSC No. | Carbon Atoms per Molecule | $z$* | Aniline Point (° C) | |
|---|---|---|---|---|
| | | | Experimental | Mair, Willingham, and Streiff[17] |
| 22 | 26 | +2 | 112.0 | 115 |
| 23 | 26 | +2 | 112.1 | 115 |
| 55 | 26 | +2 | 111.3 | 115 |
| 63 | 28 | +2 | 117.2 | 120 |
| 67 | 26 | +2 | 114.9 | 115 |
| 64 | 26 | 0 | 106.5 | 109 |
| 69 | 31 | 0 | 115.5 | 119 |
| 76 | 26 | 0 | 107.0 | 109 |
| 88 | 25 | 0 | 104.8 | 104 |
| 11 | 26 | —2 | 100.0 | 103 |
| 19 | 25 | —2 | 98.4 | 100 |
| 62 | 31 | —2 | 108.9 | 112 |
| 65 | 28 | —2 | 105.1 | 105 |
| 9 | 27 | —6 | 66.6 | 58 |
| 10 | 25 | —6 | 63.3 | 52 |
| 68 | 31 | —6 | 79.4 | 75 |
| 87 | 25 | —6 | 53.1 | 52 |

* $z$ from empirical formula: $C_nH_{2n+z}$.

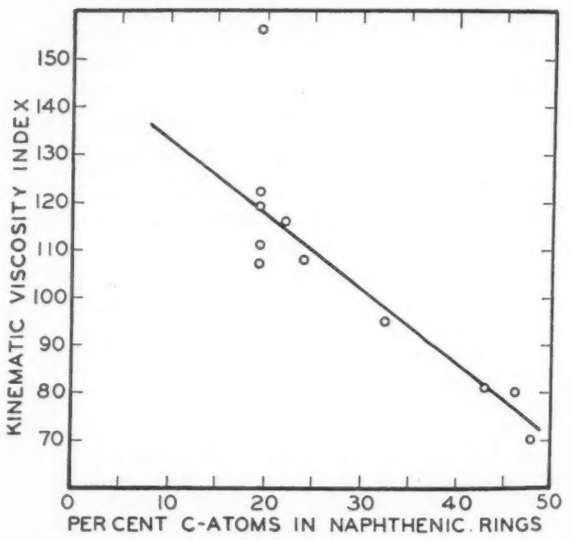



**FIGURE 12**
**Change of Kinematic Viscosity Index with Percent Carbon Atoms in Naphthenic Rings**

## Refractive Index and Molecular Refraction

Both cyclization and aromatization long have been known to increase index of refraction, and our compounds follow this general rule. Aromatic nuclei have an exaltation effect, but undoubtedly the chief cause of the refractive-index increase following cyclization is the increase in density. The experimental molecular

refractions of the hydrocarbons, which relate the densities and refractive indices, are seen to be equal or nearly equal to the values computed for the theoretical molecular formulas from Eisenlohr's atomic data. The discrepancies are greatest for the aromatics, which is not unusual.[15]

The agreement between the observed values for the refractive index at 20° C. and those calculated by the method of Lipkin and Martin[18] is very interesting (Tables 1 and 2). For the *iso*paraffins the agreement is excellent, being slightly less satisfactory for the naphthenic compounds. With only 3 exceptions, the values check within ±0.001. The computed figures are slightly high in 75 percent of the examples. Better checks may be realized (average deviation of ±0.0002) if the temperature coefficient of density used in the calculation is determined by the graphical method of Lipkin and Kurtz.[19] The calculated refractive indices listed in Tables 1 and 2 were determined using our experimental density-coefficient data.

### Density and Molecular Volume

1. In general, density increases slowly with increasing molecular weight, molecular type and symmetry remaining constant.

2. Clustering of the hydrocarbon molecule through increased branching in most cases results in greater density. That this is not a general rule is illustrated by PSC 67, 11-neopentylheneicosane, which has a smaller density than the corresponding amyl derivative.

3. As noted in the foregoing section, cyclization invariably causes a large increase in density, and aromatic compounds have considerably greater densities than the cycloparaffins with the same number of rings.

The close agreement of the experimental molecular volumes for the saturated hydrocarbons and the values calculated from Kurtz and Lipkin's[11] formula is very interesting. For only one of the examples listed is the deviation as great as 0.7 percent. The variation of the experimental molecular volume with carbon content for the various types of hydrocarbons discussed is illustrated in Figure 13. The values for the monocyclic aromatics fall very close to the line for the dicyclic naphthenes, indicating that the densities of mononuclear aromatics and dicyclic naphthenes are very similar for hydrocarbons of equal carbon content.

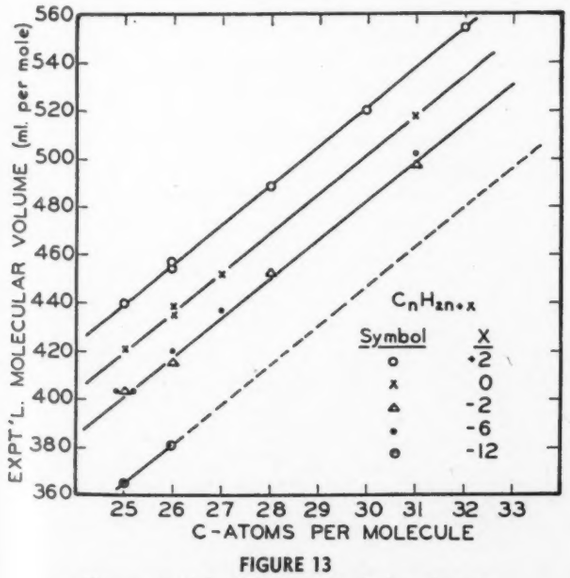



**FIGURE 13**
**Change of Molar Volume with Carbon Content**

### Aniline Point

1. Invariably aniline point increases slowly with increasing molecular weight, if the molecular type and symmetry are maintained constant (Figure 14). The average rise in aniline point per additional carbon atom is 1.7° C. for the various types of saturated hydrocarbons studied.

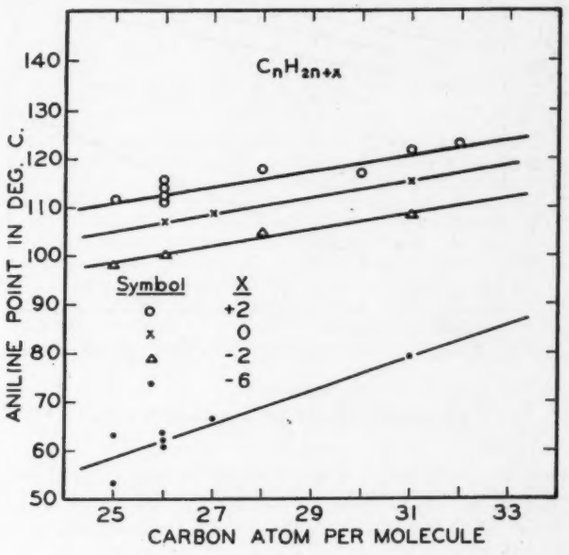



**FIGURE 14**
**Change of Aniline Point with Carbon Content**

2. The relation of aniline point to molecular type is also brought out by Figure 14. For saturated hydrocarbons the aniline point decreases with increasing cyclization, the number of carbon atoms remaining constant.

The aniline-point lowering caused by aromatization is much greater than that for the transition from *iso*paraffin to naphthene. Unlike the case of the cycloparaffinic compounds, this decrease in aniline point following aromatization is seen from the relative slopes of the curves in Figure 14 to be somewhat dependent on the percentage of carbon atoms in rings. Hence Figure 14 is a graphic foundation for the modified Waterman method used in calculating the weight percent aromatic rings presented above.

In the molecular-weight range now being studied by Project 42, the aniline points of hydrocarbons containing 2 aromatic rings are evidently very low. For the 2 hydrocarbons prepared by us which fall into this class, the aniline cloud points were somewhere below 0° C.

3. Aniline point varies inversely as the density for branching in the *iso*paraffins.

The relative change of aniline point with experimental molecular volume is illustrated in Figure 15.

### Boiling Point

1. The boiling point of a hydrocarbon invariably is increased by increasing molecular weight, molecular type and symmetry being constant.

2. Branching of the molecule is accompanied by a de-

crease in boiling point, as shown by the various *iso*paraffins listed in Tables 5 and 9.

3. In general, cyclization causes an increase in boiling point. Saturated monocyclic hydrocarbons in most

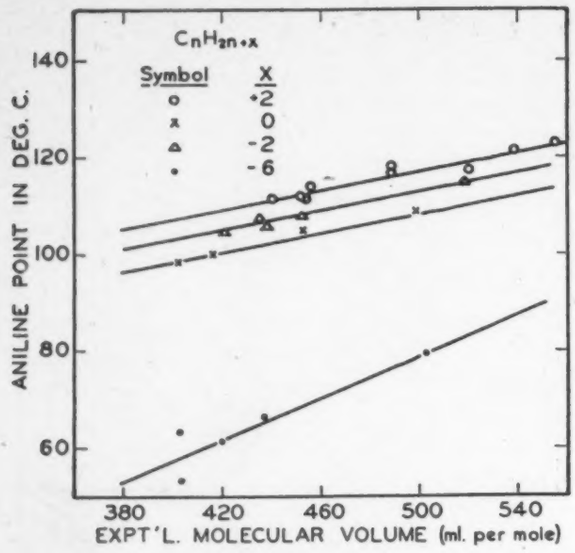



**FIGURE 15**
**Change of Aniline Point with Molar Volume**

cases have slightly higher boiling points than the corresponding mononuclear aromatics (Tables 6 and 7). This is in opposition to the conclusion of Neyman-Pilat and Pilat.[6]

4. The boiling points of the dicyclic, uncondensed hydroaromatics are equal to, or slightly lower than, the boiling points of the corresponding aromatic hydrocarbons (Table 7).

## Acknowledgment

The authors express their gratitude to the American Petroleum Institute for the funds that make this work possible. Much credit must go to Dean Frank C. Whitmore, director of Project 42, for his expert guidance throughout the course of the work. We gratefully acknowledge the assistance of our Advisory Committee: Doctors L. C. Beard, Jr., George Calingaert, L. M. Henderson, and L. A. Mikeska.

For the determination of some of the physical properties, Project 42 had the valuable assistance of Doctors M. R. Fenske, M. R. Cannon, and G. H. Fleming of The Pennsylvania State College.

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# The Thermofor Catalytic Cracking Process

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Socony-Vacuum Oil Company, Inc.

COMMERCIAL catalytic cracking of petroleum as practiced today is a comparatively recent development. It has only been during the last decade that this type of processing has attracted the widespread interest of the petroleum-refining industry. Now due to the great importance of catalytic cracking in the production of such important war materials as aviation gasoline, butane-butylene hydrocarbons, aromatic hydrocarbons, and butadiene, the commercial application of catalytic cracking has received an enormous impetus as a result of the war effort.

Starting about 1927 Eugene Houdry was one of the pioneers in this field, and as a result of his early investigations gained strong backing by Socony-Vacuum Oil Company, Inc., and the Sun Oil Company. This group, working together through their respective research, development, and engineering organizations, attained notable success in developing catalytic cracking to the commercial stage. The first commercial Houdry cataltyic cracking units were placed in operation in 1936; and since that time the Houdry[1] process has been accepted widely, and is used in the petroleum industry for producing motor fuels, aviation gasoline, and numerous allied products. The advantages of catalytic cracking were recognized quickly by the petroleum industry; and, as a result of further intensive development work, particularly during the past five years, new types of processes have attained commercial status in this field.

### Present Commercial Processes

At the present time the major catalytic cracking processes and interests may be listed as follows:

| NAME | Type | Principal Development Organizations | Licensors or Licensing Agents |
|---|---|---|---|
| Houdry..... | Static catalyst.... | Houdry, Sun, Socony-Vacuum | Houdry Process Corp.; E. B. Badger and Sons Co.; The Lummus Co.; Bechtel-McCone-Parsons |
| Fluid..... | Moving catalyst... | Standard (New Jersey) and subsidiaries; Standard (Indiana); M. W. Kellogg Co.; The Texas Co.; Universal Oil Products Co.; and Shell | M. W. Kellogg Co.; Universal Oil Products Co. |
| Thermofor... | Moving catalyst... | Socony-Vacuum..... | Houdry Process Corp; E. B. Badger and Sons Co.; The Lummus Co. |

By the end of 1943, it is estimated that these processes will have an installed charging capacity to the catalytic reactors of approximately a million barrels per day. The Thermofor catalytic cracking process —commonly referred to as the TCC process—represents one of the modern developments in this field. It is the purpose of this paper to acquaint the petroleum industry with the TCC process, describe some of its salient features, and to point out its relationship to the above-mentioned contemporary processes. However, before proceeding with a detailed discussion of the TCC process, it will be interesting to describe how Houdry, fluid, and TCC fit into the broad technical field of catalytic cracking.

**THE Thermofor catalytic cracking (TCC) process is one of the major new developments in the art of catalytic cracking. The process development has been carried through the semi-commercial stage in a 500-barrel-per-day plant to the present design of commercial units ranging in oil-charging capacity from 2,500 to 10,000 barrels per day. The process operates on the principle of continuous catalyst flow through the reaction zone, with the catalyst circulating continuously through separate systems which form a complete cycle of cracking and revivification. The separate reactor and regenerator units are designed for efficient utilization of cheap catalysts and for flexibility of operation.**

**The TCC process is inherently suitable for both catalytic cracking and catalytic vapor-phase treating. Although developed, prior to the war, for cracking to produce high-octane motor gasoline, the process is equally adaptable, both in the present emergency and in the post-war period, to the production of high-octane aviation gasoline. In addition to gasoline, the process yields substantial quantities of other valuable products such as the butane-butylene fraction for alkylation-plant charge, $C_5$ hydrocarbons, aromatics, and heating oils.**

**Important features of the plant design may be summarized as: low construction and operating cost, extensive use of conventional refinery equipment, low requirements of strategic materials, the use of low-pressure blowers instead of compressors for supplying the regeneration air, conversion of regeneration heat to high-pressure steam, and adaptability to small- as well as large-scale refineries. This paper presents a general description of the TCC process and its relation to other existing commercial catalytic cracking processes, viz., the Houdry and fluid catalyst processes.**

**This paper was presented to the Division of Refining, before the Twenty-third Annual Meeting of the American Petroleum Institute, Chicago, November 11, 1942.**

### Basic Types of Catalytic Cracking

Catalytic cracking reactions may be classified broadly according to the physical state of both the catalyst and the reacting hydrocarbons in the reaction zone. The hydrocarbons may be reacted in either the vapor or liquid phase, whereas the material acting as a catalyst may be a solid, liquid, or vapor. In the present commercially important processes for catalytic cracking, viz., the Houdry fluid, and TCC, the hydrocarbons are substantially vaporized and cracked in the presence of solid catalysts.

Many types of catalysts have been developed for use in these three processes, but at the present time

contact- or adsorptive-type materials—comprising chiefly silica-alumina compositions, made by synthesis or by the chemical treating of natural clays—are used almost exclusively for this purpose. In this paper these types of materials will be assumed as the catalysts under consideration, and they may be

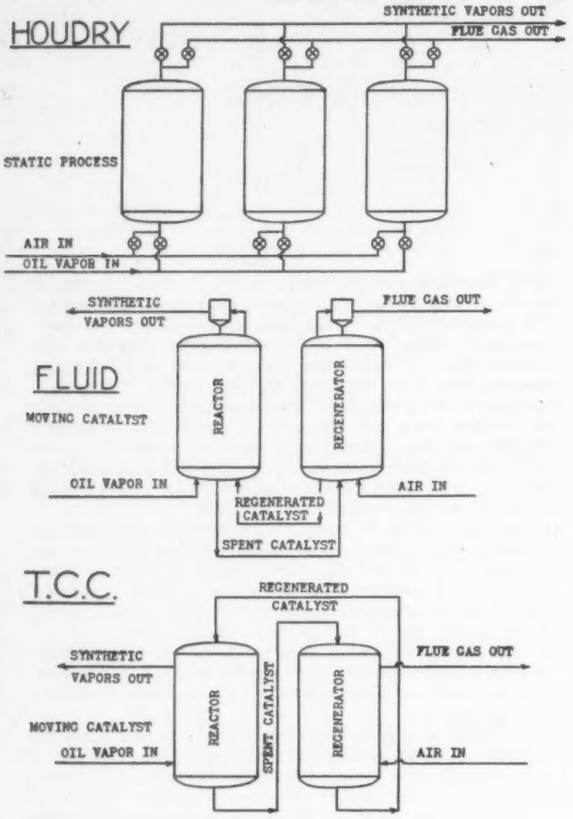


**FIGURE 1**
**Simplified Flow Diagrams of Houry, Fluid, and TCC Processes**

referred to as either "synthetic" or "clay" catalysts. Catalysts of this type are used commonly in the form of granules, powders, or pellets ranging in particle size from about ¼-inch to a few microns.

Cracking processes employing solid-type catalysts may be divided further into two basic types, according to the method of applying the catalyst:

1. Reaction systems, in which the catalyst contact mass remains static in the reaction zone and the vapors pass over the fixed catalyst bed: Houdry units exemplify this type.

2. Systems in which the catalyst moves continuously through the reaction zone: TCC and fluid units are in this class.

Simplified flow diagrams of these types of operation are shown in Figure 1.

Both the static- and moving-bed systems are designed commercially to provide continuity in the flow of oil to the cracking plant; and in this respect the Houdry as well as the TCC and fluid operations can be classed as "continuous" processes. However, technical men view the differences in the manner of handling the catalyst as the most significant distinguishing characteristic of these processes, and for this reason generally have accepted the terminology which calls the fixed-bed type (Houdry) "static" processes, and the moving-bed type (TCC and fluid) "continuous" processes. This terminology is used in this sense hereafter in this paper.

### Common Characteristics of Present Processes

Because the TCC, Houdry, and fluid processes employ the same fundamental type of cracking reaction, they have several charactertistics in common. For example, in all three types of units exposure of catalyst to oil vapors under cracking conditions fouls the catalyst with a carbonaceous deposit (commonly referred to as "coke"), which greatly reduces the catalyst activity and requires removal to restore the catalyst to its proper level of activity. This deposit is removed from the catalyst by combustion with air. On the basis of commercial units with a capacity of 10,000 barrels per day, the amount of coke burned may vary from 20 to 120 tons per day, depending on the type of operation being conducted. Continued use of the catalyst at high temperatures causes it slowly to lose activity, and replacement of the catalyst is required either continuously or periodically. The performance of the processes is dependent, to an important extent, on the amount of catalyst used relative to oil, activity of the catalyst, soaking time, temperature, and pressure.

Having these basic features in common, the differences between TCC, Houdry, and fluid processes lie chiefly in the physical methods employed in handling the catalyst, in contacting the oil and catalyst, and in regenerating the catalyst. Commercial units reflect the ingenuity of development engineers who have arrived at three distinct practical schemes for performing these operations, all of which are fundamentally sound.

Before proceeding with a detailed description of the TCC process, a brief summary of the Houdry and fluid operating principles is presented for comparison. In view of the fact that the product-distillation and feed-preparation equipment used in all catalytic cracking plants are of rather conventional type, the following discussion will be limited to the catalytic cracking and regeneration systems proper. It is assumed throughout this discussion that the charge to the catalytic reactor is delivered at proper temperature and pressure, and that the synthetic crude from the reactor will pass to a suitable distillation and stabilizing plant for the preparation of products and recycle stock.

### Houdry—Static Units

Houdry units comprise three or more catalyst-containing vessels, called "cases," manifolded together by suitable piping and valving so that one or more of the cases may be on stream while the remainder are being regenerated. The vapors and air streams are switched from case to case by a precisely synchronized valve timing system. A complete typical cycle for a given case in a 3-case unit involves 10 minutes on stream, 10 minutes valving and purging, and 10 minutes burning. By staggering the operation of the cases so that one case is always on stream, the flow of oil is maintained continuously through the system. Units having a charging capacity of 10,000 barrels per day usually have 4 or more cases, whereas larger units may employ 12 cases. The catalyst in the cases remains as a fixed bed ("static"); and, as the cases alternate between burning and on-stream operations, it is necessary to provide a heat-transfer system in the cases to maintain the catalyst temperature at proper levels. This is accomplished

by circulating a heat-transfer medium, usually molten salt, through finned heat-transfer tubes extending through the catalyst mass. By maintaining the heat-transfer medium at proper temperatures, normally 800 to 900° F., the catalyst is prevented from attaining heat-damaging temperatures while it is being regenerated. The catalyst is usually in the form of pills or pellets approximately 1/6-inch in diameter and length. Both clay and synthetic catalysts are employed.

### Fluid—Moving-Bed Units

The fluid process employs separate reactor and regenerator units, through which the catalyst circulates continuously, undergoing alternate reaction and regeneration. The reactor operates continuously on cracking, with the oil and catalyst streams entering and leaving at fixed points. The regenerator operates as a burning unit, with air and catalyst streams likewise entering and leaving continuously at fixed points. The catalyst employed is in the form of a powder ranging in particle size from about 300-mesh down to a few microns. In the reaction system the powder catalyst is mixed intimately with oil vapor, and this mixture flows through an enlarged reaction zone. On leaving the reactor, the spent catalyst first is separated from the vapor in cyclone separators, and then transferred to the regenerator. The operation of the regenerator is similar to that of the reactor, except that the catalyst is carried by air and flue-gas streams. Cottrell-type precipitators are employed to recover fine catalyst particles not recovered in the cyclone separators. Although details of the process have not been published, the foregoing is apparent from the patent literature.

### TCC—Development

The TCC process derives its name from the Thermofor type of clay-burning kiln which is employed as the catalyst regenerating unit. The Thermofor kiln* and the TCC process both were developed by engineers of the Research and Development Division of Socony-Vacuum Oil Company, Inc. The first commercial installation of the Thermofor kiln for percolation clay burning was placed in operation early in 1939, and since that time 5 additional unuits have been installed and operated for that purpose. These units have given excellent performance in service as clay burners. Prior to the time the Thermofor kiln reached the commercial scale, work on continuous catalytic cracking embodying the broader principles of the TCC process already had been well advanced, and the need for an efficient catalyst-regenerating unit had been appreciated fully. In view of this need, the adaptation of Thermofor kilns to TCC service offered a logical and attractive course to follow, and started the commercial development of the TCC process to a fully integrated continuous catalytic cracking operation.

The large-scale development work on TCC has been conducted in a semi-commercial unit having a reactor charge capacity of 400 to 500 barrels (42-gallons) per day. This unit has been operated for almost 2 years for a study of the variables of the process and for the development of improvements in equipment. The design of numerous commercial units now under construction is based on developments proved in this equipment, supplemented by extensive fundamental laboratory studies.

* The Thermofor kiln is licensed for regenerating petroleum decolorizing absorbents by the Max B. Miller Company, 501 Fifth Ave., New York, under patent rights owned by Socony-Vacuum Oil Company, Inc.

### TCC—Type of Catalyst

In adapting the Thermofor kiln to cracking-plant service, it was necessary to provide a catalyst having flow characteristics similar to the granular percolation clays. Catalysts of this type have been developed successfully in the form of granular masses consisting predominantly of particles varying in coarseness from about 4- to 60-mesh size. In this form, the catalyst mass flows freely through properly designed equipment. Catalysts may be formed to the proper particle size by the pelleting or extruding of powdered materials, or by the crushing of large lumps.

Satisfactory catalysts must possess proper catalytic activity and at the same time be sufficiently rugged to resist mechanical breakdown in the cracking plant. The useful life of a catalyst in service is governed both by its physical strength and its catalytic stability. At present commercial catalysts used in the TCC process are prepared from especially treated natural clays which are cheap, costing only a few cents per pound, and available in large quantities. Attrition rates for these catalysts in commercial TCC units will be less than one pound of catalyst per barrel of total oil charge to the reactor. Other catalysts of the synthetic or semi-synthetic type show considerable promise for future use.

### Flow in TCC Units

Referring to the simplified TCC flow diagram (Figure 2), it will be noted that the catalytic part of a TCC plant comprises separate reactor and regenerating system through which the catalyst is circulated continuously. In this respect the TCC and fluid processes may be regarded as similar; but the similarity ends here, because the two processes differ widely in principle of operation. This will be apparent from the following detailed description of flow in a TCC plant.

Starting with the catalyst hopper (Figure 2) located directly above the reactor, the clay flows downward by gravity through an elongated clay feed pipe, which supplies catalyst to a distributing hopper immediately above the reaction zone. Catalyst flows from this distributing hopper through several distributing pipes to the top of the main catalyst bed in the reactor. From this point the catalyst gravitates downward through the reactor countercurrent to the oil vapors, which enter at the bottom of the reaction zone. The reaction zone contains iron baffles designed to provide intimate contact between the vapors and catalyst, without interference with the uniform flow of the catalyst. At the top of the reaction bed, vapors are released from the catalyst mass, in which mass are contained several flues which collect the vapors from the reaction zone proper and conduct them through the top part of the catalyst bed into the open space immediately above. Below the oil inlet there is a purge zone, likewise containing baffles, in which the spent catalyst leaving the reaction zone is purged of oil vapors by means of superheated steam. After having been purged with steam in the bottom of the reactor, the spent but purged catalyst is released through a valve and flows into a conveyor, where it is carried to the supply hopper of the Thermofor-type kiln used for regenerating the spent catalyst.

From the kiln supply hopper, the spent catalyst flows through distributor pipes to the top of the catalyst bed in the kiln burning zone. It then passes downward by gravity flow through the burning zone

of the kiln countercurrent to the air supplied for burning. In this zone the carbonaceous deposit is removed from the catalyst by combustion with air. A number of special types of TCC kilns have been developed for catalyst regeneration, but for practical purposes the spiral-finned type of Termofor kiln[2] may be considered as representative. With this type, the main burning zone of the kiln is filled with a bundle of spiral-finned tubes. These tubes are designed to provide air passages up under the spiral fins, while catalyst moves slowly downward over and around the fins. Molten salt, steam, or other heat-transfer mediums may be circulated through the finned tubes to control burning, and to prevent the catalyst from attaining heat-damaging temperatures. The fins provide both air passages and heat-transfer surface. Air required for burning is supplied near the bottom of the finned tubes. Combustion gases are released from the catalyst mass by means of flues, which flues pass through the clay bed immediately above the heat-transfer system. Regenerated catalyst leaving the bottom of the kiln passes through a valve, and is picked up by a second conveyor which discharges it into the catalyst hopper above the reactor, thus completing the circuit. Catalyst flow rates through the reactor and kiln are controlled by adjusting the valves on the lines discharging catalyst from the bottom of these reactor and kiln units to the conveyors. It will be noted that regeneration of the catalyst is controlled without the recycling of flue gas or catalyst in the regeneration system.

The range of operating conditions for reactor and kiln in the TCC process is as follows:

| | |
|---|---|
| **Reactor** | |
| Temperature in reaction zone, ° F. | 750 to 950 |
| Reactor pressure, psi | 10 to 15 |
| *Space velocity | 0.2 to 3.0 |
| †Ratio of catalyst to oil | 1.0 to 8.0 |
| Steam, percent by weight of oil charge | 0 to 20 |
| **Regenerator** | |
| Regenerator temperature, ° F. | 700 to 1,100 |
| Operating pressure | Atmospheric |
| Air consumption, standard cubic feet per ton of catalyst circulated | 2,000 to 20,000 |
| Temperature of air supply, ° F. | Atmospheric to 1,000 |

* Space velocity is calculated as the ratio of volume of liquid oil charge per hour to apparent volume of catalyst mass in reaction zone.
† Ratio of apparent volume of catalyst circulated to liquid volume of oil charged per unit of time.

It will be noted that the TCC process requires only moderate temperatures and pressures, which may be attributed largely to the efficient method of reacting and revivifying the catalyst. This has been translated into a plant design that is both economical and flexible. Thus, plant construction is inexpensive, involving chiefly carbon steel and conventional refinery equipment. The process requires no compressors, the combustion air to the kiln being supplied by a low-pressure blower. The kiln itself has a variable regeneration capacity, permitting a wide choice of cracking conditions and charging stocks; and also is designed to convert the excess heat obtained from catalyst regeneration into high-pressure steam. Finally, plants can be designed in smaller sizes without serious sacrifice in economy, thus making the process attractive to small- as well as large-scale operators. At present TCC units have been designed in sizes of 2500 barrels, 5000 barrels and 10,000 barrels of charge per day to the reactor, but intermediate sizes may be designed to meet any requirement.

The high degree of flexibility of the TCC process is demonstrated by the fact that the process is equally adaptable to the production of motor gasoline and high-octane aviation gasoline.

Due to the restrictions imposed by war conditions, it is not possible to publish herein detailed data regarding the performance of the TCC process. Considerable data have been developed concerning the production of motor and aviation gasolines, which data show that the TCC process gives yields and products comparing favorably with those from other catalytic cracking processes employing similar catalysts. Although these results cannot be published for general use, they are available to potential licensees through the licensing agents for the process. However, the following discussion will give a general idea as to the type of results obtained from the process.

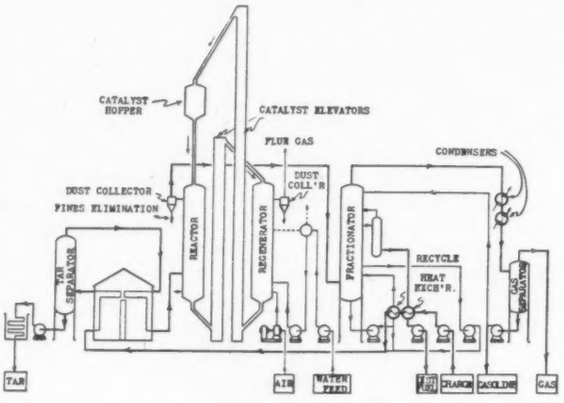


**FIGURE 2**
**Flow Diagram of Thermofor Catalytic Cracking Process**

## Motor-Gasoline Production

Motor gasoline is produced by the cracking of distillate stocks, either once-through or with recycling. Within the range of variables outlined previously, once-through operations give motor-gasoline yields of 35 to 62 volume percent on gas-oil charging stocks. Similarly, operations employing recycling of catalytic gas oils give motor-gasoline yields of 50 to 85 percent. Motor-gasoline yields of 35 to 45 percent single-pass, and of 50 to 60 percent with recycling, are representative of commercial proposals. Recycling operations are preferable, from the standpoint of ultimate yield, as the first step in the production of aviation gasolines. Typical single-pass and recycle cracking operations on gas oil are exemplified by cases "A" and "B" in Table 1. Properties of typical motor gasolines obtained from various stocks are shown in Table 2.

## Aviation-Gasoline Production

Aviation gasoline of excellent quality is produced by the reprocessing of the first-pass motor gasoline in a TCC reactor operated on a once-through basis, at somewhat lower throughput rates than in cracking. This second-pass operation, which yields 80 to 95 percent of the aviation cut present in the motor-gasoline charge, serves primarily to improve the leaded octane numbers, oxidation stability, gum stability, and aromatic content of the aviation fraction. A few general data on quality of two-pass TCC aviation gasolines are shown in Table 3.

**TABLE 1**

**Typical Yields Obtained by TCC Cracking of Mid Continent Gas Oil for Motor Gasoline**

| | Case "A" Single-Pass Operation | Case "B" 1-to-1 Recycle Operation |
|---|---|---|
| Temperature, °F | 850 | 860 |
| Pressure, psi, gage | 10 | 10 |
| **Yields on Fresh Feed** (percent by volume): | | |
| Motor gasoline, $C_4$-free | 39 | 56 |
| Catalytic gas oil | 48 | 26 |
| *n*Butane | 3 | 2 |
| *Iso*butane | 4 | 5 |
| *n*Butylenes | 5 | 6 |
| *Iso*butylene | 1 | 2 |
| Total liquid products | 100 | 97 |
| Fuel gas, $C_3$, and lighter (percent by weight) | 5 | 9 |

## Other Products

The two-pass operations described previously herein will yield, in addition to gasoline, a butylene fraction as high as 8 percent by volume of the gas oil. This can be increased considerably by cracking at elevated temperatures, without undue sacrifice in gasoline yield.

The yield of butanes, of which more than half represents *iso*butane, is generally of the order of 5 to 8 percent, and is not increased by severe cracking.

The potential yield of alkylate from the butylenes available in the total butane-butylene fraction from a two-pass TCC operation for aviation gasoline will supply a substantial portion of the total alkylate requirement for the blending of aviation gasoline to 100 octane number. In addition, the two-pass operation yields an excess of *iso*pentane concentrate over that required to pressure the total 100-octane-number blend of alkylate and base stock to 7 lb. Reid vapor pressure.

Other valuable by-products available in substantial quantity from TCC operations include: aromatic hydrocarbons such as benzene, toluene, and xylenes; naphtha fractions of high aromaticity and high octane rating; olefin-rich fuel gas, of which 35 to 40 percent by weight represents chiefly propylene plus some ethylene; and catalytic gas oil, of which from 60 to 100 percent will meet No. 2 fuel-oil specifications, depending on the end point of the gas-oil charging stock.

**TABLE 2**

**Properties of Typical Motor Gasolines from TCC Cracking on Clay Catalyst**

| | Paraffinic | Mixed-Base | Naphthenic |
|---|---|---|---|
| Source of Gasoline | Gas Oil | Gas Oil | Gas Oil |
| Gravity API | 60.6 | 60.0 | 52.7 |
| Reid vapor pressure, lb. | 9.6 | 9.7 | 9.5 |
| Doctor test | Negative | Negative | Negative |
| Mercaptan test | Negative | Negative | Negative |
| Copper-dish gum, mg | 16 | 27 | 10 |
| Glass-dish gum, mg | 1 | 2 | 2 |
| Oxygen-bomb test, hours and minutes | 12:30 | 20:30 | 8:30 |
| Color, Saybolt | +16 | +10 | +15 |
| **Octane No.** | | | |
| CFR motor method (without TEL* addition) | 76.9 | 78.1 | 82.0 |
| CFR research method: | | | |
| Without addition of TEL | 84.1 | 87.4 | 92.0 |
| With addition of 1 ml TEL per gal | 91.9 | 93.1 | 96.5 |
| With addition of 2 ml TEL per gal | 93.7 | 94.8 | 98.2 |
| With addition of 3 ml TEL per gal | 95.1 | 96.0 | 99.2 |
| **ASTM Distillation (°F):** | | | |
| Initial boiling point | 90 | 89 | 88 |
| 5-percent point | 110 | 106 | 110 |
| 10-percent point | 121 | 119 | 125 |
| 20-percent point | 145 | 140 | 156 |
| 30-percent point | 175 | 170 | 198 |
| 40-percent point | 209 | 206 | 237 |
| 50-percent point | 243 | 240 | 267 |
| 60-percent point | 276 | 268 | 294 |
| 70-percent point | 307 | 301 | 322 |
| 80-percent point | 337 | 332 | 346 |
| 90-percent point | 376 | 365 | 369 |
| End point | 404 | 398 | 410 |
| Recovery, percent | 97.5 | 97.0 | 97.5 |
| Loss, percent | 1.5 | 2.0 | 1.3 |

* Tetraethyl lead.

## Summary

From the standpoint of the national emergency, the features of the TCC process may be summed up as follows:

1. Good yields of 100-octane-number aviation-gasoline blending stocks and butane-butylene cut for alkylation-plant charge.

2. Substantial yields of by-products, including heating oils, aromatics, and propylene.

3. Low construction cost and adaptability to existing refinery equipment, bringing catalytic cracking within reach of small refiners.

**TABLE 3**

**Approximate Range of Quality of 7-Lb. RVP* Aviation Gasolines Obtained by Two-Pass TCC Processing with Clay Catalyst**

| | |
|---|---|
| Acid heat, ° F | 10 to 25 |
| Accelerated-gum test (5-hour), mg per 100 ml | 3 to 5 |
| Aromatic content, percent by volume | 20 to 30 |
| *Octane No. (AFD-1C)* † | |
| Without TEL addition | 77 to 80 |
| With addition 3 ml TEL per gal | 92 to 95 |
| With addition 4 ml TEL per gal | 94 to 97 |
| 100-octane-number alkylate blend‡ plus 4 ml TEL per gal., percent by volume of alkylate | 22 to 45 |

* Reid vapor pressure.
† AFD-1C = 1C method, Aviation Fuels Division, CFR committee.
‡ This gasoline has the necessary combustion characteristics to permit it to comply with latest aviation-gasoline specifications.

4. Low requirements for alloy steels an dother strategic materials.

5. Flexibility with respect to type of operation and character of charging stock.

6. Conversion of excess heat obtained from catalyst regeneration into high-pressure steam.

7. Adaptability to wartime and peacetime production basis.

## Future Outlook

In the post-war period the TCC process will find wide application for manufacturing catalytic motor gasoline of high quality. There appears to be little doubt that post-war gasoline manufacturing operations will find catalytic cracking displacing thermal cracking to an ever-increasing extent. Aviation-gasoline manufacture and the demand for greater qualities of butylenes probably will continue at a rate intermediate between the pre-war and wartime requirements. The TCC operation will meet these requirements in excellent fashion because of its broad range of flexibility. Likewise, with emphasis being placed on low operating and investment costs, the TCC process will maintain a strong position because of its outstanding characteristics in these respects.

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# Critical Analysis of Sweetening Processes and Mercaptan Removal

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**FACTORS affecting the applicability of the various treating processes are discussed. A simplified equation for the calculation of mercaptan removal with caustic solutions, with or without solubility promoters, is presented. Data on the extraction and stripping coefficients obtainable with natural solubility promoters extracted by caustic washing cracked and straight-run gasoline from Mid-Continent crude are given. Curves showing how the final mercaptan content affects the net treating cost in the Shell Solutizer process and in caustic washing are given. The net costs (including TEL credit based on raw gasoline) when treating to 0.002 to 0.003 percent final mercaptan-sulfur content may be one third less than when mercaptans are removed down to 0.0004 percent (doctor-sweet).**

**This paper was presented to the Division of Refining, before the Twenty-third Annual Meeting of the American Petroleum Institute, Chicago, November 11, 1942.**

IN RECENT YEARS requirements for higher octane-number gasolines and a better understanding of the factors which influence gasoline quality have caused doctor sweetening to be viewed in a more critical light, and have resulted in the development of other methods for accomplishing mercaptan conversion or the removal of mercaptans from gasoline. More recently the national emergency, and diversion of some high-octane-base stocks formerly used in motor- to aviation-grade fuels, as blending stocks, have caused refiners to be more critical of those processes which use vital chemicals and which do not add to the quality of the product.

The applicability of a given treating process depends upon a number of factors, some of which may vary appreciably in individual cases. Also, because a number of the newer processes have not had sufficient application for complete evaluation, other than by those directly connected with them, it would not be practical for us to list the various combinations of these factors for which each process is superior. It is, therefore, our purpose to discuss briefly the different types of gasoline-treating processes and the factors which should be considered in determining the applicability of a process, and to show the saving—both in cost and in consumption of strategic chemicals vital to the war effort—which could be effected by changing the mercaptan-sulfur-content specification of gasoline. In order to make our presentation more concise, consideration has been limited to those processes which have found substantial commercial application or which are of special current interest.

### Classification of Gasoline Treating Processes

Gasoline treating processes, in general, fall into 3 broad classifications: 1, those which chemically convert mercaptans to disulfides; 2, those which remove mercaptans but which do not affect materially other sulfur compounds; and, 3, those which remove some or all of the different types of sulfur compounds.

1. The first group, the oxidation processes, makes use of the fact that mercaptans may be converted to disulfides whose odors are much less objectionable. Most common of this type is the doctor-treating process.[1, 9] Others of this type are the copper-chloride,[5, 13] hypochlorite,[1] and lead-sulfide processes.[1]

2. Processes representative of the second type, currently being given most consideration, are caustic scrubbing,[1, 12, 19, 24, 30] the Shell Solutizer process,[14] and the Atlantic Unisol process.[2] The latter two processes depend upon the addition of certain compounds to increase the solubility of mercaptans in caustic solutions. Natural solubility promoters are sometimes present in naphthas, and these tend to build up in the caustic scrubbing solution—with resultant beneficial effects on mercaptan removal. As mercaptan removal results in improved lead susceptibility, the increased octane levels of motor fuels in recent years have caused the greatest attention to be focused on this type of process.

3. The third type includes acid, clay, and catalytic treating processes. Acid treating[1] of gasolines was practiced quite generally after the advent of cracking processes—before the development of oxidation inhibitors. It is sufficiently well known to preclude further discussion—except to say that it is used only when necessary to improve gum stability or to meet total sulfur specifications. Clay treating has been used for a long time, and still finds many applications when gum stability and total sulfur reduction are desired.

Catalytic treating processes[4, 17, 22] usually involve treatment of the gasoline by: *a*, vaporization of the oil; *b*, passing of the vapors through a catalyst chamber; and, *c*, fractionation of the treated oil to remove the polymers, if necessary. Some reforming may occur at at the reaction temperature. There have been improvements in these processes in recent years, mainly in the direction of higher temperatures and improved catalysts, and a number of commercial installations have been made. However, inasmuch as it is the purpose of this paper to review those processes concerned with sweetening and mercaptan removal, no detailed consideration will be given to the total desulfurization processes.

Table 1 gives a comparison of the important features of the more common processes of each of the types just described. Many variations of these processes are practiced commercially. Naturally, we do not claim that every modification is listed; rather it is intended that the tabulation shall give a general picture of the various processes.

Any comparison of the applicability of several treating processes to a given problem should consider the

following factors as of prime importance: 1, the specifications of the product; 2, the physical properties of the gasoline to be treated; 3, the chraacteristics of the various processes themselves; and, 4, their relative economics. Finally, the importance of flexibility to meet changes in specifications, in crude source, or in prcessing should not be overlooked.

## Specifications

The specifications of finished gasoline which have the most direct bearing on the type of treating process to be used are: 1, octane number; and, 2, mercaptan content. Other specifications of lesser importance include total sulfur content, copper-dish gum, and ASTM gum test.

The mercaptan content of treated gasoline in the past always has been specified by the doctor test, which requires that the mercaptan content be at or below 0.0004 percent by weight of mercaptan sulfur.[26] Recently it has been pointed out that this test is far too rigorous.[3, 25] Gasolines now are being marketed with a mercaptan-sulfur content up to 0.005 percent and higher. Some reasons for this, not discussed by Happel and Cauley,[25] are given in connection with the Shell Solutizer process and caustic washing.

With any particular gasoline, the octane-number specification determines the level to which the gasoline must be leaded. With gasolines requiring a large amount of tetraethyl lead, the mercaptan-removal processes are at a premium.

Occasionally total sulfur or gum rquirements demand the use of one of the type (3) processes (Table 1). However, with oxidation inhibitors and blending with low sulfur stocks, this necessity occurs infrequently.

## Physical Properties of the Raw Gasoline

Most important of the physical properties of a raw gasoline, in our opinion, are: 1, total mercaptan-sulfur content; and, 2, mercaptan distribution. The total mercaptan content is a consideration in all processes; its distribution affects the ease of removal by type (2) processes (Table 1).

Depending upon the type of crude and of its process-

**TABLE 1**
**Classification of Gasoline Treating Processes**

| PROCESS | Chemicals Used | Sweetening Reaction | Complete Sweetenng Effect | Regeneration of Treating Solution—Chemical Reaction | Can It Be Controlled to a Mercaptan-Sulfur Specification? | Life of Treating Reagent | Operating Temperatures and Pressures | Remarks |
|---|---|---|---|---|---|---|---|---|
| Type (1) Doctor | NaOH, PbO, S[10*] | $2RSH+Na_2PbO_2+S=PbS+RSSR+2NaOH$[1] | Yes [1] | Air blowing at 160 to 190 deg. F.[1, 20] | No | 2 to 6 months | Temperature 65 to 100° F.[9] Pressure, atmospheric. | |
| Lead sulfide | PbS, NaOH[1] | Many variations[1] | Yes [1] | ..... | No | ..... | Temperature and pressure are both at atmospheric conditions | |
| Hypochlorite | NaOCl or $Ca(OCl)_2$[1] | $2RSH+NaOCl=RSSR+H_2O+NaCl$ [1, 10] RSH converted to water-soluble sulfones and sulfoxides. | Yes [1] | Not regenerated | No | ..... | Temperature and pressure are both at atmospheric conditions [1] | Finds main use in treating natural gasoline [1] |
| Copper processes: Liquid | $CuCl_2$ | $2CuCl_2+2RSH=2CuCl+RSSR+2HCl$[13] | Yes [13] | CuCl solution is blown with air at atmospheric temperature. $2CuCl+2HCl+\frac{1}{2}O_2=2CuCl_2+H_2O$ [13] | No | ..... | Temperature and pressure are both at atmospheric conditions[13] | |
| Bed | $CuCl_2$ | Same as above | Yes [13] | Regenerated in place with with atmospheric or pure oxygen [13] Same equation as above | No | ..... | Temperature and pressure are both at atmospheric conditions [13] | |
| Slurry | $CuCl_2$, clay | $2CuCl_2+2RSH=2CuCl+RSSR+2HCl$ [5] | Yes [5] | Regenerated in place with pure oxygen [5] Same equation as above | No | 1 to 2 months [5] | Temperature and pressure are both at atmospheric conditions [5] | |
| Type (2) Caustic scrubbing | NaOH [19] | RSH dissolved in treating solution [19] | Depends upon stock.[12] | Steam stripping of treating solution.[19] | Yes | ..... | Temperature and pressure are both at atmospheric conditions [19] | |
| Shell Solutizer | KOH, isobutyric acid [14] | RSH dissolved in treating solution [14, 16] | Yes [14] | Steam stripping of treating solution [14, 15] | Yes | 3 years | Temperature and pressure are both at atmospheric conditions [14] | |
| Unisol | NaOH, methanol [2] | RSH dissolved in treating solution [2] | Borderline [3] | Distilling methanol and mercaptans from caustic, and separating alcohol and mercaptans | No | Based on loss of 0.004 percent methanol in gasoline [3] | Temperature and pressure are both at atmospheric conditions [3] | |
| Type (3) Sulfuric acid | $H_2SO_4$ [1] | RSH converted to disulfides wich are soluble in the sufluric acid [1] | Depends upon stock [1] | ..... | No | ..... | Temperature, atmospheric or colder.[1] Pressure, atmospheric | |
| Gray catalytic desulfurization | Clay [17] | Sulfur compounds converted to $H_2S$, which is removed by caustic washing or stabilization [17] | Depends upon stock [17] | Not necessary | No | About 5,000 bbl. gasoline per ton of clay [17] | Temperature, about 700° F. Pressure, moderate [17] | |
| Houdry catalytic treating | Special catalyst [22] | Sulfur compounds removed as $H_2S$ in regenerating catalyst [22] | Depends upon stock | Air blowing at 700 deg. F [22] | No | ..... | Temperature, 645° F. [22] | |
| Perco | Bauxite [4] | Sulfur compounds converted to $H_2S$, which is removed from gasoline [14, 6] | Depends upon stock [6] | Burning in atmosphere of controlled oxygen content [6] | No | 2,500 bbl. to 5,000 bbl. of gasoline per ton of catalyst without regeneration | Temperature, 700 to 750° F.[4] Pressure, 20 to 30 psi [6] | |

ing, a wide variation in mercaptan content and mercaptan distribution is possible. Table 2 gives some amounts and distributions for typical stocks. Cracked gasolines usually contain a higher proportion of low-molecular-weight mercaptans as compared with straight-run naphthas of the same boiling range. In addition, the total mercaptan content of catalytically cracked gasoline is usually low.

The mercaptan distribution may be determined by fractionation of the gasoline as described by Happel and Robertson.[24] A further refinement for analysis of the $C_6+$ mercaptans is caustic washing to determine the thiophenol content. It has been noticed that the mercaptan content of sour gasoline often decreases considerably during storage or shipment. Shipment in glass containers, and addition of about 0.5 pounds of alpha naphthol per 10,000 gallons of gasoline, prevent oxidation of the mercaptans when considerable time must elapse between sampling and analysis, as in a gasoline survey undertaken by a large refiner.

The organic-acid content affects the gum-stability properties of the gasoline, and may cause fouling of alkaline treating reagents. The effect of organic acids on caustic scrubbing is discussed in the following section of this paper.

The influence of the octane number, and of the total sulfur and oxidation stability, of a gasoline have been mentioned under "specifications."

### Characteristics of the Various Processes

The general effects of the various treating processes on the physical properties of a gasoline are fairly well known, but for easy reference are given in Table 3.

### Regenerated Caustic Washing and the Shell Solutizer Process

The work of Happel[24] and Yabroff[14, 15, 16, 23] has shown the importance of the molecular weight of a mercaptan with regard to its ease of extraction with caustic solutions. Yabroff[15] has presented a method for calculation of the amount of mercaptan removal by any given set of conditions. A somewhat simpler formula, similar to the Kremser equation[28] in gas absorption, has been derived. The equation holds for each mercaptan present in the gasoline; it is as follows:

$$\text{Percent RSH left in gasoline} = 100\left[\frac{(1-S)\ (E^a-E)V+(E-1)\ (S-S^b)K_q}{(1-S)\ (E^a-E)V+(E^a-1)\ (S-S^b)K_q}\right] \qquad \text{(Equation 1)}$$

*Where:* $S = WK_s$, stripping factor.

$W$ = steam : caustic ratio by volume; steam volume = condensate volume.

$K_s$ = stripping coefficient.

$E = \frac{K_q}{V}$, extraction factor.

$V$ = gasoline : caustic ratio by volume.

$K_q$ = extraction coefficient.

$a$ = number of theoretical extraction stages plus one.

$b$ = number of theoretical regeneration stages plus one.

Inspection of equation (1) shows that the characteristics of a treating solution which affect its ability to remove mercaptans from gasoline are its extraction and stripping coefficients.

Although the buildup of natural organic acids in caustic washing solutions has been noticed for years,[29, 30, 31] the importance of this buildup to the extraction and stripping coefficients of the caustic has been recognized only recently. These coefficients, $K_q$ and $K_s$, are plotted in Figures 1 and 2 against the number of carbon atoms in the normal mercaptans for a 10-percent sodium-hydroxide solution, a 30-percent sodium-hydroxide solution which had picked up 20 percent by volume of "organic acids" while cracked and straight-run gasolines from Mid Continent crude were being washed, and one of the Shell Solutizer solutions, *K-2*, which is 6 potassium hydroxide and 3N potassium *iso*butyrate. Organic-acid content was determined by neutralization with hydrochloric acid and measurement of the volume of the acidic layer liberated. Organic acids present in gasolines are both of the phenolic type[32] and aliphatic type.[27]

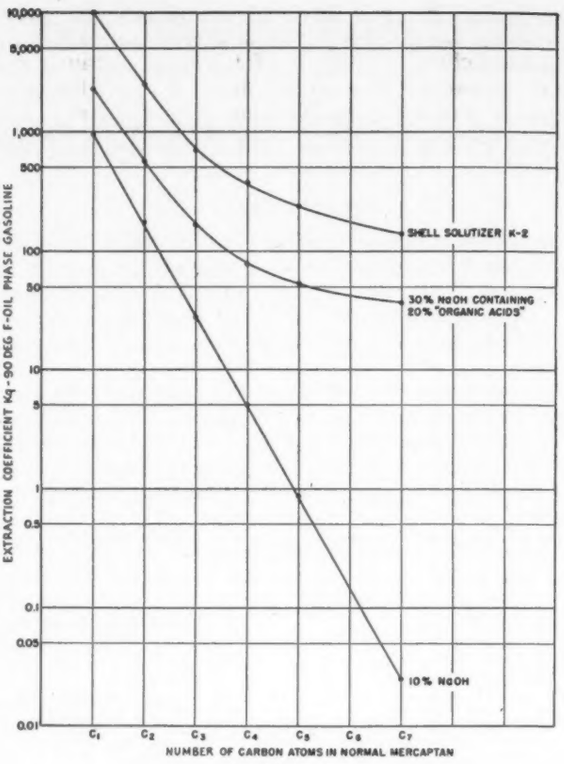


**FIGURE 1**

**Plot of Extraction Coefficient Vs. Number of Carbon Atoms in the Normal Mercaptan for Some Treating Solutions**

The inability of plain caustic solutions to remove the heavy mercaptans is evidenced by the solution's low extraction coefficient for such mercaptans. The higher extraction coefficients of the caustic solution which had picked up natural-mercaptan solubility promoters, particularly in the region of the high-molecular-weight mercaptans, remove this limitation from caustic washing. The still higher extraction coefficients of the *K-2* Shell Solutizer solution are valuable particularly when the total mercaptan content is high or when treating to very low mercaptan contents; however, the smaller values of its stripping coefficients partly offset this.

The mercaptan distribution of the gasoline being treated affects the mercaptan removal obtained under any given set of conditions. Thus, cracked gasoline containing a higher proportion of light mercaptans is more responsive to the foregoing methods of mercaptan removal than a straight-run gasoline.

Equation (1) has been used to calculate the mercap-

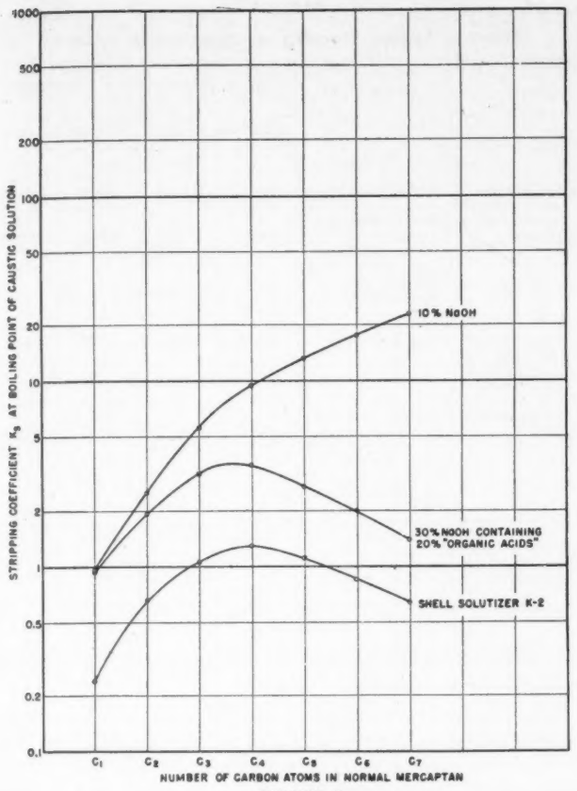


**FIGURE 2**

**Plot of Stripping Coefficient Vs. Number of Carbon Atoms in the Normal Mercaptan for Some Treating Solutions**

tan removals which can be obtained by the treatment of two gasolines with a 10-percent sodium-hydroxide and a 30-percent sodium-hydroxide solution containing 20 percent organic acids extracted from cracked and straight-run gasoline from Mid Continent crude. One gasoline was typical of straight-run gasolines in that it contained a predominance of heavy mercaptans, whereas the other was typical of cracked gasolines in that it contained chiefly low-molecular-weight mercaptans. Mercaptan distributions of these gasolines are shown in Table 4. For purposes of comparison, the same circulation rate of caustic (15 percent of the gasoline volume) and the same amounts of stripping steam (10 pounds and 20 pounds per barrel of gasoline) were used. A treating plant consisting of three mixing stages for caustic and gasoline, equalling two theoretical extraction stages, and a seven-plate regeneration tower, giving three theoretical plates, was assumed.

Calculated mercaptan-sulfur contents of the treated gasolines are shown in Table 5.

Inspection of the data in Table 5 shows that 10 pounds per barrel of stripping steam reduces the mercaptan content of the straight-run gasoline 81.9 percent when the 30-percent sodium-hydroxide solution containing 20 percent organic acids is circulated. An additional 10 pounds per barrel of steam removes only 10.2 percent more. If the cracked gasoline is treated, the same solution removes 94.4 percent of the mercaptans with 10 pounds per barrel of steam, and only 3.5 percent more when the steam rate is increased to 20 pounds per barrel. The additional mercaptan removal obtained by increasing the steam rate from 10 to 20 pounds per

**TABLE 2**

**Mercaptan Distributions of Some Typical Gasolines**

| Gasoline Type | (1) Straight-run | (2) Polyform | (3) Coking Unit | (4) Controlled Coil Cracking Unit, Synthetic Charge | (5) Controlled Coil Cracking Unit, Crude Charge | (6) Controlled Coil Cracking Unit, Crude Charge | (7) Houdry | (8) Straight-run | (9) Houdry | (10) Straight-run | (11) Vapor-Phase | (12) Houdry | (13) Straight-run | (14) Thermal-cracked | (15) Thermal-cracked | (16) Vapor-Phase |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Crude | Mid-Continent | | | | | | | Kansas | | Mid-Continent | | | | | East Texas | |
| Boiling range, ° F | 100–275 | 100–400 | 100–400 | 100–400 | 100–400 | 100–400 | 100–400 | 100–300 | 100–400 | 100–400 | 100–400 | 100–400 | 100–400 | 100–400 | 100–400 | 100–400 |
| Percent of total mercaptan content: | | | | | | | | | | | | | | | | |
| Methyl | 3.9 | 16.5 | 12.4 | 6.4 | 13.1 | 34.2 | 16.0 | 8.5 | 3.4 | 21.3 | 35.6 | 58.1 | 3.1 | 18.6 | 15.1 | 13.4 |
| Ethyl | 15.7 | 30.8 | 21.9 | 10.9 | 21.9 | | 17.0 | 6.7 | 6.5 | 7.1 | 29.1 | | 5.3 | 33.7 | 15.8 | 23.4 |
| Propyl | 30.6 | 29.0 | 24.9 | 13.4 | 20.0 | 21.2 | 8.0 | 11.5 | 5.3 | 11.0 | 9.3 | 11.3 | 10.0 | 10.0 | 19.7 | 19.8 |
| Butyl | 45.2 | 9.6 | 23.6 | 6.2 | 15.6 | 14.2 | 8.0 | 17.7 | 3.5 | 11.3 | 7.0 | 7.4 | 16.0 | 14.8 | 14.9 | 10.4 |
| Amyl | 4.6 | 9.4 | 15.6 | 11.1 | 10.9 | 11.8 | 8.0 | 55.6 | 5.8 | 10.5 | 4.6 | 3.1 | 12.2 | 9.5 | 6.9 | 6.8 |
| Thiophenols | .... | 4.7 | 1.6 | 0.0 | 18.5 | 0.0 | 43.0 | .... | 61.7 | 38.7 | 14.4 | 20.1 | 8.2 | 12.5 | 27.5 | 26.2 |
| Hexyl and heavier | .... | | | 43.7 | | 18.6 | | .. | 13.8 | | | | 45.2 | | | |
| Total | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 |
| Mercaptan sulfur in sample, percent by weight | 0.009 | 0.080 | 0.090 | 0.006 | 0.020 | 0.018 | 0.0090 | 0.0099 | 0.0117 | 0.0093 | 0.0314 | 0.0089 | 0.0078 | 0.020 | 0.035 | 0.020 |

**TABLE 3**

**Effect of Treating Processes upon Physical Properties of Gasoline**

| PROCESS | Octane No. | TEL Susceptability | Inhibitor Susceptability | Total Sulfur | Doctor Test of Treated Gasoline | Gum Content | Remarks |
|---|---|---|---|---|---|---|---|
| Doctor | Decreases [9, 11] | Decreases or no change [9, 11] | Decreases or no change [9, 21] | Increases [1] | Sweet | ..... | ..... |
| Copper | No change [5, 13] | No change [5, 13] | Good [13, 21] | No change [5, 13] | Sweet [5, 13] | No change [5, 13] | Large increase in inhibitor requirement if any copper remains in gasoline [5] |
| Hypochlorite | Decreases [10] | Decreases [10] | Poor [10] | May be decreased [1] | Sweet [1] | Increases [1] | ..... |
| RSH removal | Increases [2, 3, 5, 11] | Increases [2, 3, 5, 11, 12] | Good [7, 21] | Decreases [2, 3, 14] | Can be controlled | No change [7] | Alkyl-phenol content of treated gasoline must be controlled [7] |
| Catalytic and total sulfur removal | Increases [6, 7, 11] Decreases on acid treating [12] | Increases [6, 11, 17, 18] | Good [17, 22] | Decreases [1, 6, 17] | Depends upon stock [1, 6, 17] | Decreases [1, 22] | ..... |

**TABLE 4**

**Typical Mercaptan Distribution of Raw Gasolines from Mid-Continent Crude**

| MERCAPTAN | PERCENT OF TOTAL MERCAPTAN CONTENT | |
|---|---|---|
| | Typical Straight-run Gasoline | Typical Cracked Gasoline |
| Methyl | 4 | 19 |
| Ethyl | 3 | 34 |
| Propyl | 13 | 18 |
| Butyl | 19 | 15 |
| Amyl | 18 | 9 |
| Hexyl* (assumed heptyl) | 40 | 5 |
| Total | 100 | 100 |
| Total mercaptan-sulfur content, percent by weight | 0.0265 | 0.0357 |

**TABLE 5**

**Effect of Caustic Washing on Gasolines in Table 4**

| Treating Solution | Operating Conditions | MERCAPTAN-SULFUR CONTENTS (Percent) | | | |
|---|---|---|---|---|---|
| | | Straight-run Gasoline | | Cracked Gasoline | |
| | | Before | After (Calculated) | Before | After (Calculated) |
| 10 percent sodium hydroxide. | Treating-solution circulation rate: 15 percent of gasoline volume. Stripping steam: 10 lb. per bbl. of gasoline. | 0.0265 | 0.0173 | 0.0357 | 0.0083 |
| 30 percent sodium hydroxide containing 20 percent of organic acids. | Same as above. | 0.0265 | 0.0050 | 0.0357 | 0.0020 |
| 10 percent sodium hydroxide. | Treating-solution circulation rate: 15 percent of gasoline volume. Stripping steam: 20 lb. per bbl. of gasoline. | 0.0265 | 0.0172 | 0.0357 | 0.0076 |
| 30 percent sodium hydroxide containing 20 percent of organic acids. | Same as above. | 0.0265 | 0.0023 | 0.0357 | 0.0008 |

barrel is even less in each case when the 10 percent sodium hydroxide is circulated.

More complete data, showing the effect of increased final mercaptan content on stripping-steam requirements when the Shell Solutizer process is used, have been supplied by Shell Development Company. These data are presented in Table 6.

Inspection of the data in Table 6 shows that the stripping-steam requirement rises sharply when washing to very low mercaptan contents. Also it will be noted that the recommended caustic circulation rate increases when washing to low final mercaptan contents, and when gasolines containing a high proportion of heavy mercaptans are treated, as in straight-run gasoline or heavy cracked naphthas. Comparison of the data on item No. 5 shows that the more expensive plant, i.e., the one containing 6 extraction stages, requires only a 25-percent reagent circulation rate and 25 pounds to 30 pounds of steam per barrel of gasoline, as compared to a 50-percent circulation rate and 40 to 50 pounds of steam per barrel in the plant with only 3 extraction stages, when running to 0.0004 percent residual mercaptan sulfur. This steam saving in the more expensive plant is not so great when a higher final mercaptan content is allowed.

Comparison of the data in Tables 5 and 6 shows that, in general, the steam savings realized by the use of a better treating plant, i.e., one with more extraction and stripping stages, or a better treating solution—i.e., such as Shell Solutizer solution against sodium hydroxide with or without any natural solubility promoters—are larger as the treating job becomes more difficult. The relative difficulty of the treating operation increases as the sour stock has a higher mercaptan content, or as the proportion of high-molecular-weight mercaptans increases, or as the allowable final mercaptan content is lowered. In other words, the better the plant or solution, the lower the final mercaptan content to which it is possible to treat before the stripping-steam requirement increases sharply.

Not all gasolines contain enough acids to cause them to build up to 20 percent of the caustic solution even when using strong caustic solution, although some will cause much higher buildups. Mason, Bent, and McCullough[3] report concentrations up to 50 percent by weight of the caustic solution. Higher concentrations of natural solubility promoters will give larger extraction coefficients, although the increased viscosity of the solution may cause difficulties in operation of the treating plant. When starting with weaker caustic solutions, the free caustic strength may decrease far enough during the acid building to cause the extraction coefficients to fall off. Naturally, the use of a pure acid such as *iso*butyric, which has been selected especially for its effect on the extraction coefficient, will give higher extraction coefficients than the naturally occurring organic acids in gasoline.

As stated previously, the presence of mercaptans in gasoline results in decreased tetraethyl-lead susceptibility. The work of Ryan[11] puts this decrease on a quantitative basis. He shows that the percentage decrease in lead susceptibility due to mercaptan sulfur becomes relatively greater at low concentrations of mercaptans. Thus, increasing the mercaptan content of a gasoline from 0.0000 to 0.005 percent of mercaptan sulfur results in a greater percentage decrease than increasing

**TABLE 6**

**Effect of Increasing the Residual Mercaptan-Sulfur Content on the Treating Requirements in the Shell Solutizer Process**

| Item No. | TYPE OF GASOLINE | EXTRACTION TEMPERATURE = 90° F: Boiling Range (° F) | Sulfur: Total Mercaptan, Percent by Weight | | SOLUTIZER SOLUTION = K-2 OR EQUIVALENT: Number of Extraction Stages | Solutizer Solution—Gasoline-Volume Ratio to Give Residual Mercaptan-Sulfur-Content Percent by Weight: 0.0004 | 0.002 | 0.005 | Stripping Steam* (Pounds per Barrel of Gasoline Treated to Give Residual Mercaptan-Sulfur Content) Percent by Weight: 0.0004 | 0.002 | 0.005 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Blend† | 100–400 | 0.097 | 0.027 | 6 | 0.15 | 0.05 | 0.02 | 15–20 | 5 | < 5 |
| 2 | Cracked | 230–415 | 0.79 | 0.064 | 6 | 0.85 | 0.32 | 0.20 | 50–65 | 20–25 | 5 |
| 3 | Cracked | 100–400 | 0.36 | 0.090 | 6 | 0.12 | 0.03 | 0.01 | 20–25 | 5 | < 5 |
| 4 | Straight-run | 125–350 | 0.141 | 0.051 | 6 | 0.80 | 0.36 | 0.25 | 50–65 | 20–25 | 10–15 |
| 5 | Straight-run | 100–260 | 0.151 | 0.085 | 3 | 0.50 | 0.20 | 0.10 | 40–50 | 15–20 | < 5 |
| | | | | | 6 | 0.25 | 0.12 | 0.06 | 25–30 | 10–15 | < 5 |

* Type II stripping[15] (indirect), 10 theoretical plates, atmospheric pressure: does not include steam required to supply sensible heat or to make up for radiation of other losses.
† 35 percent by volume of straight-run; 65 percent by volume of cracked.

the mercaptan-sulfur content from 0.020 to 0.025 percent, although the amount of mercaptan added is the same in both cases. Both decreases in lead susceptibility are based upon the susceptibility of the sulfur-free gasoline. The additional tetraethyl-lead fluid required to reach a certain octane number for a given decrease in lead susceptibility depends upon the lead level to which it is necessary to go. The amount of TEL solution saved is greater at high lead levels than at low.

Thus the factors of stripping steam and lead saving

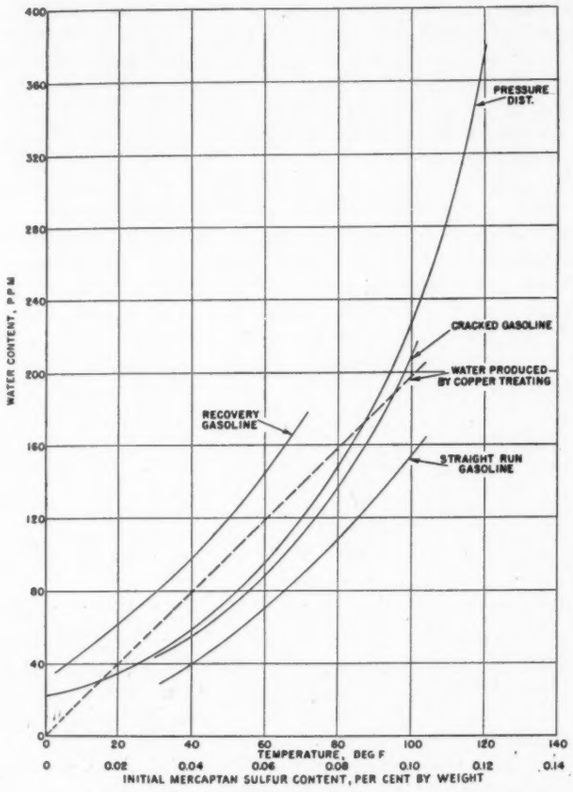


**FIGURE 3**

**Solubility of Water in Gasolines and Amount of Water Produced by Copper Treating of Gasolines of Various Mercaptan-Sulfur Contents**

are interrelated. Increased expenditures of stripping steam decrease the final mercaptan content and effect an increased lead saving. This point is discussed further in the section dealing with economic comparisons.

The concentration of alkyl phenols, which is an important factor in the gum stability of a gasoline, may be controlled by adequate prewashing and by maintaining a suitable concentration in the Shell Solutizer solution.[7] Another method of controlling the concentration of alkyl phenols is to add the desired amount of them to the treated gasoline after they have been recovered from the prewash.

## Copper Treating

Unlike caustic washing and the Shell Solutizer process, doctor and copper treating are not affected to any great extent by the mercaptan distribution. The total mercaptan content is of much more importance.

Chemicals consumed in the copper processes are mainly oxygen and reagent. The slurry process requires pure oxygen in about 1 to 1½ times the amount called for in the sweetening reaction. The oxygen is dissolved in the gasoline before it contacts the slurry. The solubility of oxygen in the gasoline is a limiting factor in the use of this process, because undissolved oxygen increases reagent carry-over from the treating vessel. The liquid process depends upon air blowing for regeneration and, of course, has no oxygen cost. The various solid or bed processes use either air or pure oxygen, depending upon the stock and process. Carryover of reagent and incomplete regeneration due to fouling of the reagent affect the amount of copper used.

The water is formed in the overall sweetening reaction, i.e., $2RSH+\frac{1}{2}O_2=RSSR+H_2O$. With high mercaptan contents, the amount of the water formed exceeds that soluble in the gasoline, and accumulates in the reagent. This water interferes with the proper operation of any but the liquid treating process, and must be removed. Drying the untreated gasoline with rock salt or by chilling, and increasing the solubility of water in gasoline by heating the gasoline, have both been used successfully for this purpose. Figure 3 shows the amount of water formed when gasolines of various mercaptan contents are treated. The solubility of water in several Mid-Continent gasolines at different temperatures also is shown in Figure 3. Copper treating is applied usually to gasolines with less than 0.05 percent mercaptan sulfur.

Cracked gasolines have a tendency to retain small amounts of copper which seriously affect the gum stability of the gasoline. Sodium-sulfide washes and the addition of metal deactivators have minimized this difficulty; spent-caustic prewashes for hydrogen sulfide have been used for sodium-sulfide washes.

Ryan[11] has shown that equal weights of mercaptan or disulfide sulfur have the same effect on tetraethyl-lead susceptibility, but that disulfide sulfur has a slightly more detrimental effect on octane number than the corresponding mercaptans. Thus copper treating, in which mercaptans are converted quantitatively to disulfides, results in a slight decrease in octane number with no change in lead susceptibility.

## Doctor Treating

In estimating costs and chemical consumptions for a proposed doctor plant, most refiners use their own data and experience. The caustic and sulfur consumptions are connected directly with the mercaptan content of the stock. Although the litharge cost can vary from almost nothing in a well operated and designed plant to almost stoichiometric proportions in a poorly operated plant, certainly the litharge cost is affected by the sourness of the stock.

Important considerations in evaluating the doctor process are the product loss in blackstrap and increased tetraethyl-lead consumption due to decreased lead susceptibility. Ryan[11] shows that the addition of only 0.002 percent by weight of sulfur as t-butyl tetrasulfide results in a decrease in octane number of 0.5 units. Approximately six times this amount of sulfur as t-butyl trisulfide is required to produce an equal effect. As stated previously, only a slight decrease in octane number results from conversion of mercaptans to the corresponding disulfides. The same effect is encountered with the lead susceptibility. Mercaptan and disulfide sulfur have the same effect. Sulfur as polysulfide sulfur has the same effect as 2.29 times this amount of sulfur as disulfide, or mercaptan sulfur, in decreasing the lead susceptibility. The importance of avoiding polysulfide formation, particularly tetrasulfide formation, during doctor treatment is clearly evident.

## Unisol Process

The Unisol process stands midway between caustic washing and the Shell Solutizer process, on the one hand, and doctor and copper treating, on the doctor. It

is relatively insensitive to the mercaptan distribution and the total mercaptan content. The recommended reagent circulation rate, 2.0 percent by volume of caustic and 0.8 percent by volume of methanol, is the minimum compatible with efficient operation of the process, and

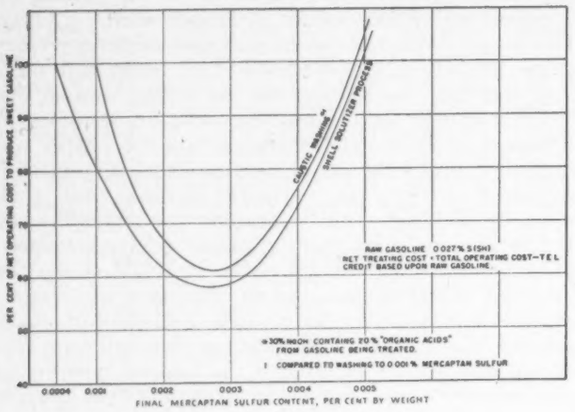
PER CENT OF NET OPERATING COST TO PRODUCE SWEET GASOLINE
CAUSTIC WASHING
SHELL SOLUTIZER PROCESS
RAW GASOLINE 0.027% S (SH)
NET TREATING COST = TOTAL OPERATING COST—TEL CREDIT BASED UPON RAW GASOLINE
30% NaOH CONTAINING 20% "ORGANIC ACIDS" FROM GASOLINE BEING TREATED
1 COMPARED TO WASHING TO 0.001% MERCAPTAN SULFUR
0.0004
0.001
0.002
0.003
0.004
0.005
FINAL MERCAPTAN SULFUR CONTENT, PER CENT BY WEIGHT

**FIGURE 4**
**Plot Showing the Effect of Final Mercaptan Content on Net Treating Cost**

is sufficient to treat gasolines containing up to 0.07 percent of mercaptan sulfur or more. Pilot-plant and full-scale data indicate that this amount of reagent will produce a gasoline either doctor-sweet or just on the borderline. Full-scale operation has produced some early difficulties which, for the most part, have been overcome.

In the design of the full-scale plants operating on the Unisol process, provision has been made for increasing the caustic circulation rate to 4.0 percent. In actual operation, however, the 2.0 percent figure has not been exceeded. In view of the fact that this minimum reagent circulation rate is maintained, the steam cost is fixed at that amount necessary to strip all the methanol from the reagent and to recover the methanol from the water-alcohol mixture from the mercaptan separator. Hence, the final mercaptan content is fixed at that figure to which this amount of reagent will scrub the gasoline, and no saving would be effected by increasing the allowable mercaptan content of the finished gasoline. With stocks that are more sour, requiring a higher circulation rate, some saving might be effected. However, as the process never has been tried on such stocks, no actual data are available.

The induction period of the treated gasoline is controlled by carrying the correct amount of alkyl phenols in the treating solution.

The only methanol loss in the process is the slight amount, 0.004 percent by weight,[3] which is carried away in the exit gasoline. No methanol loss should be encountered in disposing of the mercaptans taken overhead with the methanol, when the water concentration is controlled.

## Economic Comparisons

Consideration of the characteristics of the various treating processes, and a knowledge of the gasolines and other conditions prevailing at a particular refinery, will help the refiner to make a choice of the several processes which look favorable. A preliminary comparison based upon steam cost, tetraethyl-lead cost, and royalty is often valuable in eliminating all but those processes which are worthy of full consideration in a particular instance.

Next a complete economic comparison of these processes should be made. Unit costs can be obtained from the licensors of the various processes. Tetraethyl-lead credit or debit can be either calculated or measured. The discussion of each process should aid in making this comparison.

In regard to the cost picture of caustic washing and of the Shell Solutizer process, ideally the increased operating cost necessary to wash to low mercaptan contents should be balanced against the lead savings at each mercaptan level. In this way, provided the gasoline odor is satisfactory, the refiner should determine the mercaptan content to which his gasoline should be treated. Happel and Cauley[25] have shown that, from an odor and corrosion standpoint, 0.005 percent mercaptan sulfur is permissible in most cases. Even in congested areas with many multi-car garages, it should not be necessary to go below 0.002 percent because of odor considerations.

In order to illustrate the savings which might be effected by the choice of the proper final mercaptan content, the cost of treating to various final mercaptan contents by caustic washing and the Shell Solutizer process has been calculated. The results are plotted in Figure 4 as the percent of the cost of complete sweetening vs. final mercaptan contents. Inasmuch as the doctor and copper processes operate satisfactorily only when a sweet product is being produced, no curve can be shown for these processes. Similarly, a curve for the Unisol process might be drawn only for a gasoline with a much higher initial mercaptan content. No data on this possibility are available at present.

The gasoline used for these comparisons was a blend of 65 percent cracked and 35 percent straight-run gasoline from Mid-Continent crude. Principal characteristics of the gasoline are tabulated in Table 7.

Utilities, repairs and maintenance, and chemical costs were obtained from the licensors of the Shell Solutizer process. Caustic-washing requirements were estimated the same as those of the Shell Solutizer process except for the items of steam and chemicals. Stripping-steam consumption was estimated from equation (1) and by comparison with data on the Shell Solutizer process. Tetraethyl-lead savings at 72 octane number were determined at the doctor-sweet and 0.005-percent mercaptan-sulfur levels, and calculated for intermediate points. The gross operating cost at each mercaptan level was credited with the tetraethyl-lead saving based on the raw gasoline. Labor costs were assumed the same for each process. Royalty and plant-depreciation costs were not included in the calculations.

A glance at Figure 4 will show the large savings possible when a mercaptan-sulfur content between 0.001 and 0.004 percent is specified instead of the doctor test. Naturally, the minimum point on these curves will fall at different points for different gasolines, but the same general effect should be noted in all cases. In general, the size of the plant required and the stripping-steam consumption are out of proportion to the additional tetraethyl-lead saving realized when the doctor-sweet

**TABLE 7**
**Characteristics of Mid-Continent Gasoline Blend**
65 Percent Cracked—35 Percent Straight-run

| | |
|---|---|
| Boiling range, °F | 100–400 |
| Mercaptan-sulfur content, percent by weight | 0.027 |
| Total sulfur content, percent by weight | 0.097 |
| ASTM octane No.: | |
| Without addition of TEL | 63.5 |
| With addition of 1.0 ml TEL per gallon | 69.7 |
| With addition of 2.0 ml TEL per gallon | 72.6 |
| With addition of 3.0 ml TEL per gallon | 74.5 |

specification is used in connection with one of these processes.

When one considers that the doctor specification is too severe with respect to gasoline odor, that small amounts of mercaptan do not affect the stability of the gasoline if the alkyl-phenol content is controlled, and that meeting this specification increases the treating cost considerably, the usefulness of the doctor test as a gasoline specification is seriously questioned. In view of the present national emergency, the continued expenditure of large amounts of vital chemicals such as litharge, caustic, and tetraethyl lead to meet an arbitrary test does not seem to be justified.

Once the economic comparison has been developed, the final choice of a treating process can be made. In making this choice, the flexibility of the process to fit in with future developments naturally should be taken into account.

## Trends in Gasoline Treating

A review of technological advances in refinery processing, showing how these advances have been followed by variations in treating methods, is given as an indication of what may be expected:

1. When only straight-run gasoline was produced, treatment was almost entirely by the doctor process.
2. With the invention of cracking, it was necessary to use sulfuric acid or clay treating, prior to doctor treatment, to obtain the desired gum and color stability.
3. By the use of gum inhibitors, the need for acid or cleay treatment was reduced considerably.
4. Discovery of tetraethyl lead and studies of the effects of sulfur compounds upon tetraethyl-lead susceptibility,[11] along with a better understanding of the factors which influence gasoline quality, have depreciated the doctor process, and have stimulated searches for other processes.
5. Increases in octane levels of motor fuels were accompanied by development of the copper-chloride-treating and mercaptan-removal processes.
6. Catalytic processes also have been extended to gasoline treating operations.

Some examples of recent changes or trends which also may influence treating operations are:

1. Increase in total sulfur specification of gasolines from 0.10 to 0.25 percent. This will allow wider use of high-sulfur oils, or will decrease the treatment required.
2. More widespread use of catalytic, alkylation, and polymerization processes. This will tend to increase the proportion of cracked gasolines which may be treated satisfactorily by mercaptan-removal processes because of their more favorable mercaptan-sulfur distributions.
3. Changes in crudes processed. These are not always predictable or anticipated but, if known, should not be underrated in their effect upon treating problems. Indications are that higher-sulfur crudes will come more into the picture in the future.
4. Elimination of the doctor test and substitution of a maximum mercaptan-sulfur content as a gasoline specification. The lack of significance of the doctor test long has been appreciated and discussed.[25] Elimination of this test has been suggested to the government as a measure for the conservation of strategic war materials and of tetraethyl lead.


## Acknowledgment

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# Natural Gas and Natural Gasoline in the War Effort

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IN THE beginning may I respectfully urge your remembrance of the fact that while the natural-gas and natural-gasoline phases of the petroleum industry may be relatively small, they are important segments and vital to the war program and to the public welfare. Natural gas does a very big and important job. It touches practically every phase of the war-production program. It is used to keep our fighting men warm, used in preparing their food, and for heating the water to keep them clean and healthy. It is used in hundreds of higher industrial processes all along the war-production stream, and its components provide an important part of fighting fuel.

### Releases Other Fuels for War

Since 1938 the send-out of natural gas for industrial and commercial purposes has increased by more than 10 percent per year. Indications are that this year will exceed last year by 25 percent, and in some areas as much as 40 percent. Natural-gas consumption in the United States for the year 1942 will probably approach 3 trillion cubic feet. It will exceed that in 1943. For the purpose of comprehension through comparison, it may be stated that 3 trillion cubic feet of 1000 Btu natural gas is approximately equivalent in heat energy to 124 million tons of coal, 879 billion kilowatt-hours of electricity, or 540 million barrels of fuel oil.

I would also call your attention to the fact that this tremendous volume of energy must be consumed largely within the nation, and cannot be exported. Therefore, the greater market served by natural gas in the nation, the more oil there will be available for export to the fighting forces of the United Nations and for usage in markets not at this time served by this superb fuel.

The problems of the natural-gas and natural-gasoline industries are in large measure the same problems that are faced in production, transportation, refining, distribution and utilization of oil and its many by-products. As regards natural gas, it differs from oil only in that it is a well-to-burner operation. Therefore, reserves to balance supply with demand must be developed and kept in formation in readiness for a rush call to meet high peak demands. With the exception of a few places where underground storage is maintained, there is no major means of storing natural gas close to the great critical industrial centers in the nation today.

### War Problems

The problems resulting from the impact of war include:

1. Increased demands by both war industries and private industries, as well as the normal increase of about 12 percent in normal civilian usage.
2. Lack of materials to expand facilities in keeping with these increasing demands.
3. Increasing shortage of man power brought about by enlistments, induction into the armed forces, and migration of workers to other war industries.
4. Increased expenses resulting from the rising cost of labor, materials, and operating supplies.
5. The heavy tax burden, present and prospective, in the view of expenditure of tremendous sums of money in order to supply demands of the war effort.
6. Ascertaining the expected requirements of natural gas, natural gasoline, and related hydrocarbons by all phases of the war effort in time to provide for them.
7. The need for relief during the war period from express or implied covenants contained in leases by reason of limited supplies of critical materials which prevent the orderly drilling of wells on such leases.

### Appalachian Region

The Appalachian region, which includes such great industrial centers as Pittsburgh, Toledo, Cleveland, Columbus, Akron, Dayton, Charleston, and others, contains about 6 percent of the proved natural-gas reserves of the nation, and the market served equals 18 percent of the nation's natural-gas sales. M-68 was relaxed as respects the drilling of gas wells in this area. As a result of the recent drilling program in this region, it appears that there will be only a few areas within the region where actual shortages will appear on peak-load days during the coming winter. With the drilling of less wells, there has been developed a greater deliverability than during the previous year. In the very near future, however, if the war markets in this region are to be adequately served by natural gas, thus freeing oil for other uses, there is no doubt that there will be need for increased transportation facilities from the great reserves of the Southwest.

### District 2

In District 2 are located such large and important industrial centers as Detroit, Chicago, Minneapolis, St. Paul, Omaha, St. Louis, and Kansas City. For the most part, gas to supply these large and important markets is transported through long trunk-line systems originating in the reserve areas of the Texas Panhandle, Oklahoma Panhandle, and southwestern Kansas, or in the fields of Louisiana and Texas. Ability to supply the demand is limited only by the deliverability of existing pipe-line systems.

As respects other markets not attached to these

trunk-line systems, the greater part of the gas produced and marketed is being produced from old fields that are now nearing depletion, and from which gas is being taken during peak load at peak deliverability.

The Michigan gas supply is largely an intrastate situation; and, while they have adequate supplies at the present time, their reserves are relatively small when compared with the markets served.

Illinois has practically no marketable gas. Oklahoma is producing almost entirely from highly depleted pools. There are some new pools, such as the Cement area and the deeper sands in the Chickasha area, but the demands on these fields indicate that their depletion will be rather rapid. The old pools of Kansas appear to be from 50 to 80 percent depleted. In this area, and in western Missouri and northeastern Oklahoma, the provisions of M-68 were relaxed to allow as great a development as possible to take care of the current winter's requirements.

### Pipe-Line Construction

There will be peak-day curtailment in many parts of this district, and the shortage of fuel oil for standby service is becoming acute. Indications are that in this district, within the next 18 months, there will have to be some major pipe-line construction if adequate supplies are to be maintained. In the meantime we are encouraging the exploration of new areas within a reasonable distance of main transmission lines where such lines will be able to transport additional gas to meet the peak loads.

### Curtailed Drilling

The prospects for new discoveries of any new major gas reserves in this area do not, at this time, appear very encouraging. By reason of this overall condition in District 2, we have had to deal with a situation prevailing in the Hugoton field located in western Kansas and the Panhandle of Oklahoma. As you all know, this field constitutes about the largest single unified gas reserve in the world, and relatively little gas has been withdrawn from it to date. The occurrence of gas in this field is so uniform and regular that a producing well is almost certain to be encountered in any location in the field. Something over 300 wells have been drilled, and there are about 28 to 30 wells that have been drilled but are not at this time connected to market outlets. The potential gas available from the wells already drilled is more than sufficient to supply the demands of all the pipe lines dependent upon the field for their supply. Notwithstanding this, drilling operations continued in the field. The recent supplement to Conservation Order M-68 has curtailed all further drilling operations in this field without the approval of the Office of Petroleum Coordinator for War.

### Proration Program

It is the consensus of opinion that, in order to conserve critical materials as well as the gas reserves of the field, a proper proration program must be put into effect. The Natural-Gas and Natural-Gasoline Division has sponsored joint action by the state regulatory commissions of the states of Oklahoma and Kansas, looking toward a solution to this problem. These agencies are approaching an agreement on the form of a uniform proration order to be issued individually by them for the portions of the field in respective states. The administration of the orders will be by the cooperative action of the two commissions and will have the effect of regulating operations in the field as a single unit. This will permit efficiency in the conservation of both critical materials and gas reserves, and will result in making use of most of the gas wells already in existence but not yet connected to markets.

As far as practicable, in encouraging such orders, we recognize that any attempted proration should be predicated on the most direct and least complicated approach, giving reasonable recognition to the correlative rights of the owners of reserves in place and least interference to the withdrawal of gas in keeping with varying seasonal needs.

### Large Fuel Reserve

South of latitude 39, west of the Mississippi River, north of the Gulf of Mexico and Rio Grande River lies the nation's greatest fuel reserve. In the case of natural-gas reserves, it contains the equivalent of something over 70 percent of the total. In the case of production of natural gasoline and related hydrocarbons, the percentage would be greater. It is one of the most important training areas for our armed forces in the country. It is likewise an area in which there is tremendous war-industry activity. It is the region to which we must all look for the greatest source of supply for oil, natural gas and natural gasoline, and related hydrocarbons, because new discoveries of production in this area are generally more prolific than in other areas of the nation. It is the area in which the greatest encouragement for new exploration and development should prevail.

In this area there are large reserves of distillate and large concentrated gasoline-plant capacity producing the largest available supply of natural gasoline and related hydrocarbons which are so critical to the war needs.

The plants of this industry perform a great service in normal times in conserving what would largely be waste products of great value, and in this war period this service can become vital as they make up the deficiency of hydrocarbons at the plants of those refiners who are turning out necessary war materials.

### District 4

District 4, comprising the Rocky Mountain states, is the least densely populated of any of the districts. It supports many industries vital to the war program. Large volumes of natural gas are used in the smelting and refining of non-ferrous metals, the production and refining of oil, and the refining of beet sugar. Many new military establishments are also dependent upon gas for fuel. Except for gas from the Panhandle field of Texas, transported for utilization in Colorado, the area is largely self-sustaining from the standpoint of natural-gas supply.

### District 5

District 5, the Pacific coastal area, being separated as it is from the remainder of the country by the Rocky Mountains, is entirely dependent on gas produced within the immediate environs. California, the only large producer of natural gas in the district, has the largest number of gas consumers of any state in the union, and is the only large producer of natural gas that does not export or import any of this natural fuel. Because California's natural-gas pro-

duction is predominantly casinghead gas, increased demands and scarcity of critical materials have resulted in unusual problems.

In order to conserve gas produced in association with oil in excess of summer demands and utilize it to meet peak demands during winter months, there was needed an adequate storage. As a result of cooperative study of the California Railroad Commission, local oil and gas operators, and the Office of Petroleum Coordinator, it was determined that the partly depleted Playa del Rey oil pool had characteristics suitable to use for gas storage.

Upon recommendation of the Office of Petroleum Coordinator, the Playa del Rey reservoir, located close to the center of the gas distribution system of the Los Angeles Basin area, has been taken over by the Defense Plant Corporation, and will be operated as a gas-storage reservoir to be used primarily as a source of supply to meet emergency peak-load conditions. Geological studies of the structure indicate that the capacity of the field will be approximately 3 billion cubic feet. Of this, 1 billion cubic feet will be allowed to remain in the formation as a pressure backlog, and 2 billion cubic feet will be available for current storage. Three miles of 12-in pipe has been laid from the Southern California Gas Company's 26-inch main line. This line has already been connected to the injection wells, and gas is being injected in small amounts at line pressure of approximately 160 pounds, pending the installation of a compressor plant.

Among the major developments of District 5 during the past year are:

1. Conversion of the Stanpac line from a gas line to an oil pipe line, and the subsequent rearrangement and addition of natural-gas facilities to handle additional gas from the Rio Vista gas field to the San Francisco area.

2. The general increase in crude-oil production, and particularly the shifting to more low-gravity crude at low gas-oil ratios to get greater fuel-oil yields. This program necessitated some changes in gasoline-plant facilities and gas-handling facilities.

3. The increased demand for *iso*butane was met by full cooperation of gasoline-plant operators in increasing their plant efficiencies and providing facilities for maximum recovery of *iso*butane. Our last report indicates about 97 percent of *iso*butane is being delivered to manufacturers of 100-octane.

4. To conserve all gas production, a gas conservation committee, under the direction of the production committee, and assisted by the natural-gas and natural-gasoline committee, has produced most excellent results. The investigation made every operator conscious of the problem and, by voluntary cooperation, practically all of the existing situations have been or will shortly be corrected.

5. Through the cooperation of the production committee, with the natural-gas and natural-gasoline committee, the production of natural gas is being regulated to meet the gas demands. The fact that only two fuels are generally available in California, viz., fuel oil and natural gas, presents an immediate problem due to the need for accumulating maximum stocks of fuel oil for war purposes. This requires that the maximum fuel need of industry in the district be met with natural gas, and requires the maximum production of casing-head gas to meet the requirements in southern California.

### Conservation for War

Conservation is the biggest word in the supply phase of the war effort. Likewise, when we talk about the conservation of oil and gas, we are talking about the life span of the oil and gas industry. When we deal with it, we are dealing with the industrial future of the nation, and with the health, comfort, and future of our citizens.

Conservation of natural-gas reserves, and conservation in the production, transmission, and utilization of natural gas, must be faced positively by all of us. Sound policies must be encouraged, and sound laws and their proper enforcement be sincerely advocated. The importance of proper utilization of gas produced with oil calls for continued support of studies designed to permit the proper use, in an orderly manner, of the gas produced with oil, which heretofore has been blown into the air and wasted.

The war emergency will cause many dislocations in our operations, but, on the credit side, dire necessity will teach us much about better production methods, better transportation and distribution methods, better ways and means not only of conserving the product, but of preventing the economic dissipation of it.

This war is the first thing before the house. Victory in it will strain our resources, require our best talents, and utilize the maximum of our energies. Its prosecution requires the utmost conservation of critical materials which, in our industry, means largely metals and particularly steel. This being true, I should like to emphasize that, in our considerations in the Natural-Gas and Natural-Gasoline Division, we are proceeding on the theory that the most effective promotion of the war program demands the minimum expenditure of critical materials consistent with proper and adequate development of gas reserves and resources required—and only as required—for such program.

### Considered Recommendations

Our recommendations will be made after cautious study, with a view to determining whether or not additional gas is needed for the immediate future, or on an overall development program designed to drill a specific number of wells necessary to meet required deliverability. We feel that this policy may be expected to contribute to the most effective promotion of the war program.

We are not approaching our job as a dubious experiment, but with a sincere effort to grasp the facts intelligently, analyze them, and take speedy and objective action on them.

The great petroleum industry is one of the most important segments in the whole war effort. We are interdependent in meeting the emergencies of the hour, the day, and the indefinite period of a very serious war effort. The overall problems before all of us, more and more, will require prompt and thorough consultation, reasoned and competent analysis, and intelligent planning. I think this has been rather well effected already. Shall we mutually pledge continued cooperation?

# Corrosion Protection of Storage Tanks

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**FOR a number of years extensive work has been carried on developing methods of corrosion protection for steel storage tanks. Galvanized roofs have shown a life double that of plain steel for less than double the cost. Galvanized tanks, in small sizes, have shown merit. Aluminum roofs have given good service, but are costly, particularly when aluminum rafters are used. Various coatings, including aluminum and lead foil, paints, enamels, synthetic resins, etc., generally have been unsatisfactory, although they afford some protection for a short period. Use of outside rafters on small tanks has resulted in reduced replacement costs. The use of spent caustic, when corrosion is due to aqueous solutions of hydrogen sulfide, has given good results. Electrolytic corrosion of tank bottoms has been controlled successfully by cathodic protection. Most of the foregoing methods of protection require the use of critical materials not available for such use.**

**Concrete has been employed for many years as protection for various parts of tanks. Successful methods of applying reinforced gunite linings are described and illustrated. These have been applied successfully when the tank was in such corroded condition that replacement was the only alternative. Costs per square foot are 40 cents for roof and structural members, 37½ cents for the shell, and 35 cents for the bottom—these totaling about half the cost of a new tank. The use of unreinforced gunite lining for protection of floating-roof tanks also is described.**

**Gunite protection of storage tanks appears to be the most feasible means of preventing corrosion and maintaining storage tanks for the duration of the emergency.**

**This paper was presented to the Division of Refining, before the twenty-third annual meeting of the American Petroleum Institute, Chicago, November 11, 1942.**

OWING to the existing shortage of steel plate, protection of oil-storage tanks against corrosion is a matter of timely interest. For a number of years, extensive work has been carried on developing methods of corrosion protection for steel storage tanks. The need for such protection has been due primarily to the severe corrosion from sour stocks. Although severe corrosion has been experienced in crude tanks, the greatest need for increased life has been for tanks handling the lighter distillates. However, this study of corrosion protection has been carried on not only by refineries, but by producers, because of the fact that short life has been experienced in lease and other producing tanks due to the severe corrosion experienced. In numerous cases, smaller-size steel tanks have required major repairs within two years and complete replacement in less than four years, both in refineries and in the producing fields.

The Texas Company has submitted considerable data on galvanized tanks and tanks with galvanized roofs and other parts. It has submitted also some data concerning aluminum roofs—all of which are included in its report appended hereto as Apendix I. Although some of these data are conflicting, it appears that the life of a galvanized roof is about double that of a plain steel roof, and this additional life more than offsets the additional cost. It also appears that there are savings from reduced cleaning costs due to less deposits as compared to those on plain steel roofs, and also due to elimination of exterior roof painting. Aluminum roofs appear to give quite satisfactory service, but are costly, particularly when aluminum rafters are used. The Texas Company feels that, when aluminum becomes more available after the present emergency, it should be considered for tank roofs.

The Humble Oil and Refining Company reports that aluminum roofs installed on numerous rundown tanks have given satisfactory service with the exception of being difficult to maintain in a vapor-tight condition. Its initial cost of these aluminum roofs was between two and three times as much as steel roofs and, after several years' experience with them, it became doubtful if they could be justified economically, as the tanks were subject to being transferred to sweet service for a number of years at a time with a resultant tie-up of the added investment in the aluminum roofs. This objection, of course, would not apply if the tank were constantly in sour-stock service.

The Texas Company also submitted data on the use of aluminum and lead foil as protective coatings for roofs. Neither of these materials has proved satisfactory.

The Texas Company, the Humble Oil and Refining Company, and the Standard Oil Development Company all have made extensive investigations of various types of coatings — including paints, enamels, synthetic resins, etc., for protecting the interior of tanks and under side of tank roofs. Although some protection has been afforded by some of these coatings, in general they require such frequent servicing and renewal that they have not proved practical.

On smaller tanks, considerable savings in replacement of roofs can be made by the use of outside rafters; because for this construction the corrosion, due to sour gases, will affect only the roof plates and not the structural members. This apparently is not justified on the larger tanks due to the higher initial cost and maintenance. It has been reported also that

flushing the vapor space with oil at frequent intervals to give a protective oil coating also retards corrosion.

Corrosion of tank bottoms is also a problem. When the corrosion of the bottom is caused by aqueous solution of hydrogen sulfide, The Texas Company reports that excellent results have been obtained by pumping spent caustic into the bottoms of such tanks.

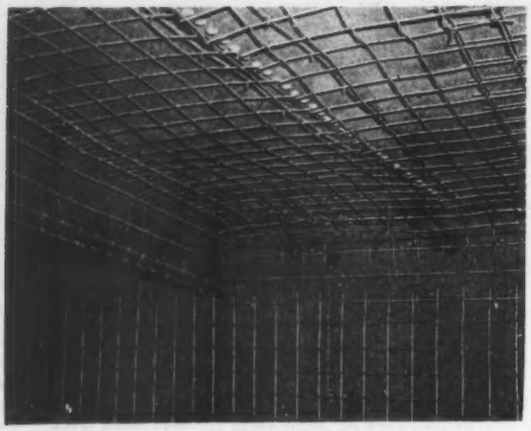


**FIGURE 1**
**General view showing reinforcing in place at junction of roof and shell, including one rafter and manner in which reinforcing is joined together at various points.**

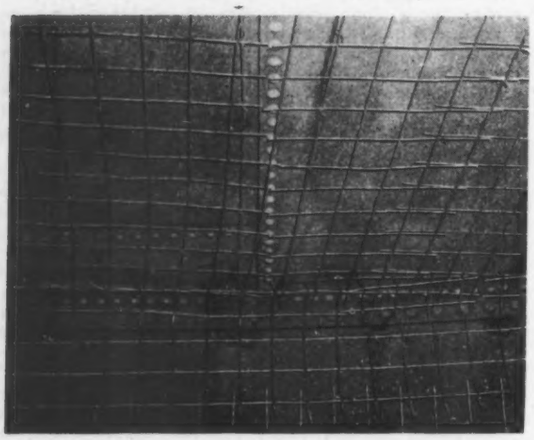


**FIGURE 2**
**View at junction of tank roof and shell along line of a weakened seam, illustrating method of cutting reinforcing.**

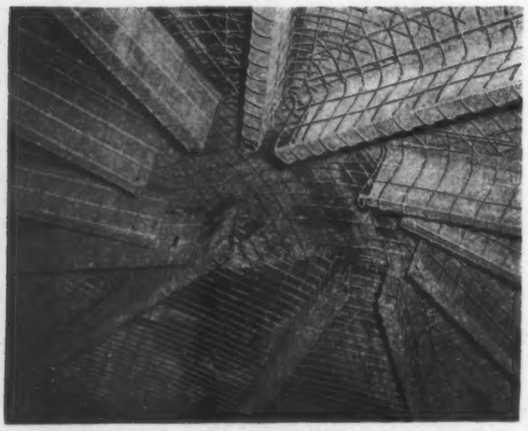


**FIGURE 3**
**View at center of roof, illustrating application of reinforcing to rafters and roof sheets.**

When the corrosion on tank bottoms is due to electrolytic action, The Texas Company reports that surveys indicate that cathodic protection is desirable on tank bottoms as well as on pipe lines and other equipment. Its report (Appendix I) goes into considerable detail concerning the application of cathodic protection and the results which have been obtained.

The foregoing methods of protection have been passed over rather hurriedly and without much detail, inasmuch as they are not applicable to present-day conditions, owing to the critical materials involved. There is, however, another method of protection which is applicable to roofs, walls, and bottoms of tanks, and that is protection by the use of gunite and concrete.

For a great many years concrete has been employed as a protection for the bottoms of tanks and even, in some cases, to repair bottoms which have corroded to the point of leakage. This protection usually consists of pouring a concrete slab on the tank bottom and applying a gunited extension for some distance up the side of the shell. Both reinforced and unreinforced slabs have been used in the bottom. When such protection was applied without reinforcing, it has not been entirely satisfactory, because it has been subject to excessive cracking. However, it has proved that, when the concrete remained intact, the steel was protected. The problem then was to find a method of installing concrete linings which would remain intact and give protection to the parts desired. Much work has been done along these lines. Figure 1 (Dixon) illustrates a gunite-lined bottom with the lining extended 2 feet up the shell and columns. The reinforcing on the shell consists of ¼-inch crimped rods, tackwelded on 18-inch centers to the shell, and this covered with 3-inch x 3-inch No. 10 gage plain welded mesh wired to the crimped rods. The bottom is reinforced with 3-inch x 3-inch No. 10 gage plain welded mesh, but without the use of crimped rods on the bottom. The gunite is applied to a thickness of about 1½ inches on the vertical surfaces and to a thickness of about 2 inches on the horizontal surfaces. The reinforcing in the bottom is lifted up with hooked rods so as to be embedded in the concrete off the bottom. Before the gunite was applied, all surfaces had been sandblasted until free from oil, dirt, and scale. The gunite mix was one part portland cement to 2½ parts of clean, coarse, sharp sand. All pipe connections were extended through the lining with nipples to prevent abrasion of the lining by the flow of oil. The Texas Company reports that installations of this type have given exceptionally good service.

Humble Oil & Refining Company has done a considerable amount of guniting of the entire interior of tanks, including the under side of roofs, rafters, walls, columns, and bottoms. The tanks thus lined have ranged in size from 30 feet in diameter by 10 feet high to 120 feet in diameter by 40 feet high. Its report is appended as Appendix II. Humble Oil & Refining Company divides the guniting of the interior of a tank into 3 different steps: 1, preparation of the surface; 2, installation of the reinforcement; and, 3, application of the gunite. All three steps are equally important.

In preparing the surface for gunite linings, the tanks first are steamed, cleaned, and made gas-free.

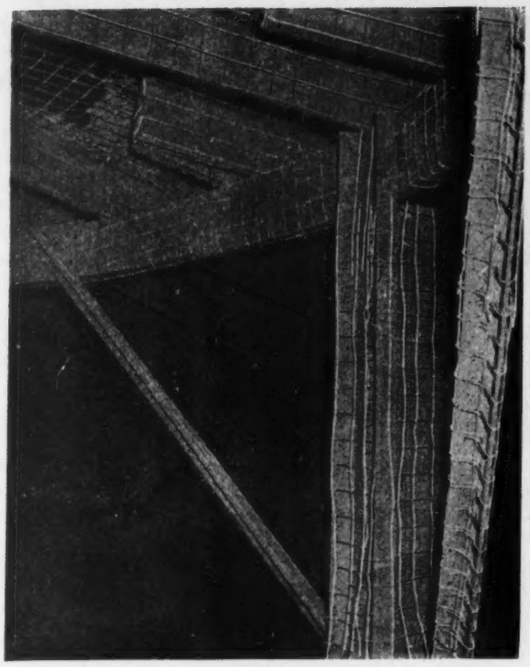


FIGURE 4
View of application of reinforcing to columns, girders, rafters, and braces.

FIGURE 5
Another view of the application of reinforcing to columns, girders, rafters, and roof.

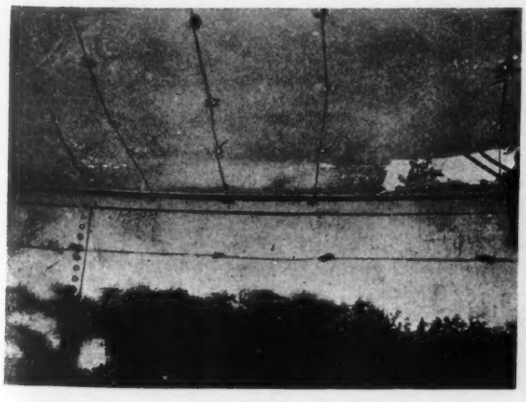


FIGURE 6
Closeup view, showing tackwelding of reinforcing rods to roof.

FIGURE 7
General view, showing tackwelding of reinforcing rods to roof.

FIGURE 8
View showing reinforcing mesh in place on roof and rafters.

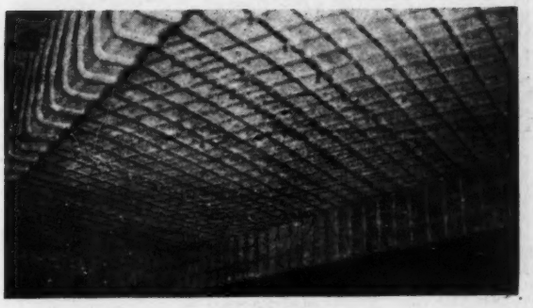


FIGURE 9
Closeup view of mesh reinforcing in place on roof and rafters.

FIGURE 10
Completed gunite application on roof and rafters.

After all dirt, oil, sludge, etc., has been removed, the metal surfaces to be gunited are sandblasted. The sandblasting operation is carried out with an operating air pressure of 100 psi, using a ⅜-inch sandblasting nozzle and graded silica sand. All surfaces are sandblasted until there is complete removal of all foreign material, including mill scale. This sandblasting operation not only assures a good bond between the steel and the gunite, but also serves to clean the steel surface, so that sound welds may be obtained where the reinforcing rods are tackwelded to the tank plates. The time required for placement of the reinforcement and guniting may be sufficient to permit the formation of some iron oxide on the sandblasted surfaces. As long as the iron oxide tightly adheres to the base metal, the discoloration of the base metal apparently does not affect the bond between the gunite and the steel.

The method of applying the reinforcing to the shell of the tank is illustrated in Figure 1 (Kelly). This reinforcing consists of ¼-inch-diameter rods placed vertically with a horizontal spacing of 18 inches. These rods are tackwelded to the shell on 18-inch centers vertically, and are sprung away from the sheets approximately ⅛ inch between each weld; 3-inch x 3-inch No. 10 gage steel-wire mesh is tied securely to the vertical rods every 9 inches with No. 16 gage tie wire. The welding is made discontinuous at door-sheet joints in order to permit removal of the door in the usual manner when the gunite is broken along the seams.

The tank bottom is reinforced by laying ¼-inch rods on 18-inch centers both ways, so as to form 18-inch squares; 3-inch x 3-inch No. 10 gage steel mesh is laid on the steel bars and tied with No. 16 gage tie wire at the corners of the squares formed by the rods. The bars are not fastened to the tank bottom. As the gunite is applied, a helper working ahead of the gunite stream uses a bent rod to pull the steel mat to the center of the gunite.

The method of reinforcing for the under side of the roof is illustrated in Figure 2 (Kelly). This reinforcing is suspended from ¼-inch rods tackwelded at 15-inch intervals, and sprung away from the roof between welds the same as is done on the shell. One

**FIGURE 11**
**Completed gunite application on roof at center column.**

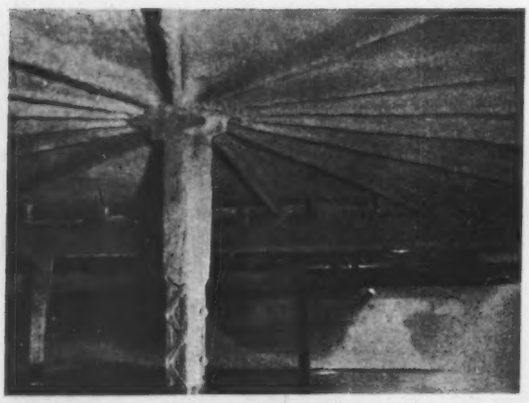


**FIGURE 12**
**Another view of completed gunite application on roof at center column.**

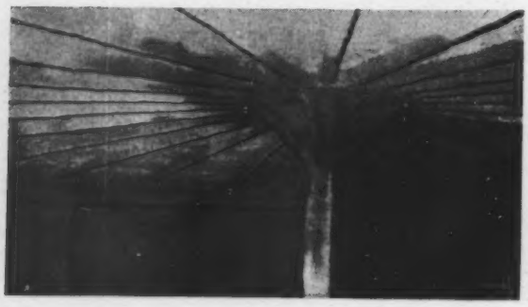


**FIGURE 13**
**Another view of completed gunite application on roof at center column.**

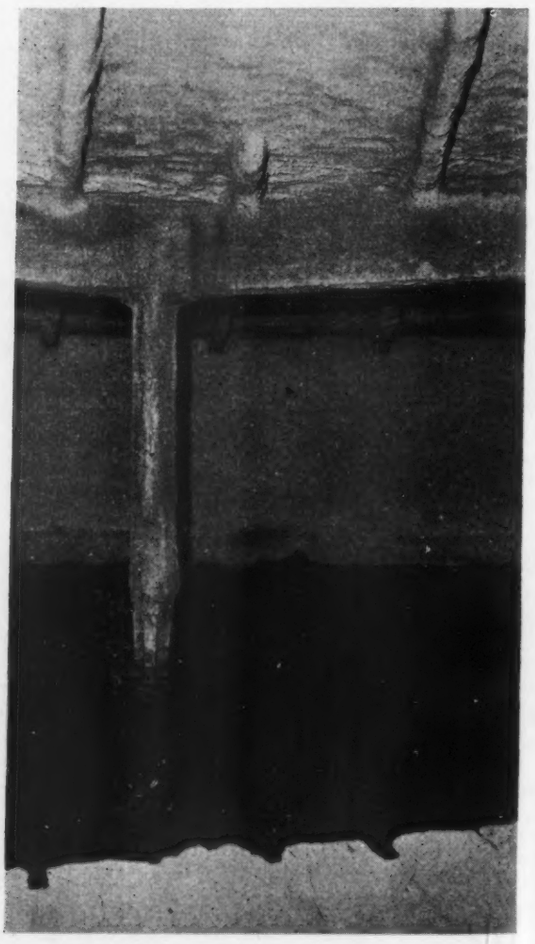


**FIGURE 14**
**Finished guniting applied to roof, rafters, and upper 5 feet of shell.**

rod is placed on each side and parallel to each rafter, and additional rods are tackwelded in each bay, with a maximum spacing of 15 inches; 3-inch x 3-inch No. 10 gage steel mesh is fitted into the rafter space and tied to the rods on 6-inch centers with No. 16 gage tie wire. The rafters are covered with 3-inch x 3-inch No. 10 gage mesh, bent to a flanged **U**-shape, with the flange consisting of at least one mesh. After fitting over the rafters, these pieces are tied securely to the reinforcing rods paralleling each rafter. When safety sections to relieve explosions are provided, the reinforcement is made discontinuous at the joints of these sections in the same manner as for the door sheets in the shell.

The method of installing steel reinforcement for structural members and tank corners is illustrated in Figure 3 (Kelly). The columns and girders are wrapped with 3-inch x 3-inch No. 10 gage mesh cut and bent to conform to their respective shapes, and securely tied at all joints with No. 16 gage tie wire. At the junctures of the roof and shell and the bottom and shell, additional mesh is installed in the form

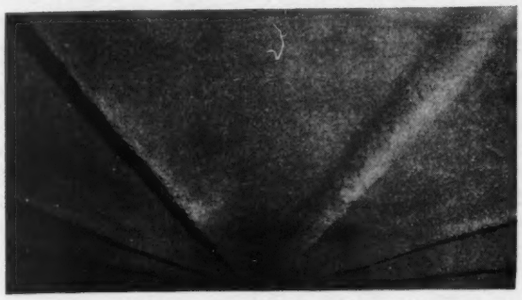


**FIGURE 15**
**Finished gunite applied on roof and rafters in vicinity of center column.**

**FIGURE 16**
**Gunite partly completed on center column.**

**FIGURE 17**
**Gunite partly applied to roof and rafters.**

**FIGURE 18**
**Another view showing gunite partly applied to roof and rafters.**

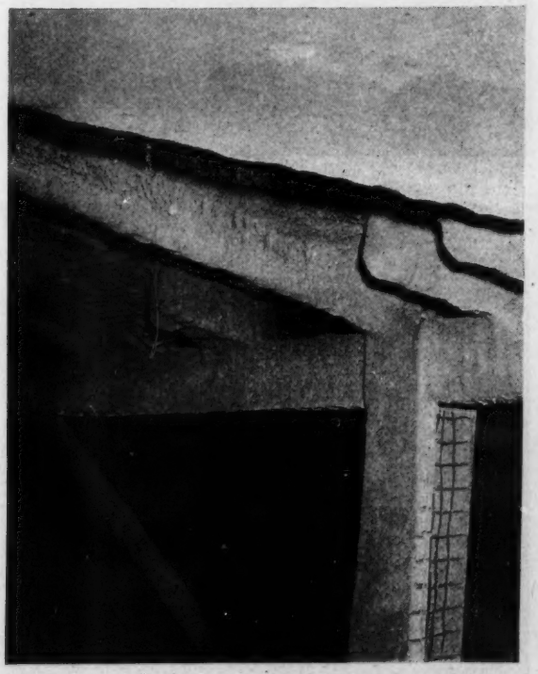


**FIGURE 19**
**Closeup view of partly applied gunite at junction of column, girder, and rafters.**

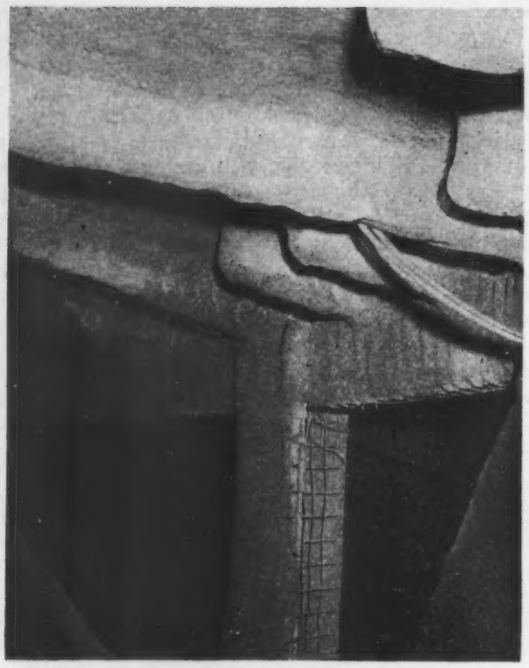


**FIGURE 20**
**Another closeup view of partly applied gunite at junction of column, girder, and rafters.**

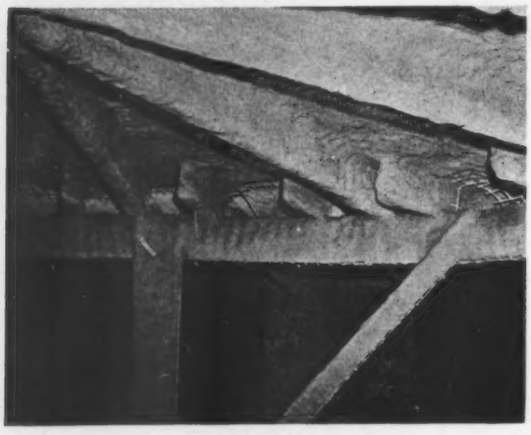


**FIGURE 21**
**Another closeup view of partly applied gunite at junction of column, girder, and rafters.**

**FIGURE 22**
**Another closeup view of partly applied gunite at junction of column, girder, and rafters.**

of an angle and tied to the reinforcing on the top, bottom, and shell.

Figures 1, 2, 3, 4, and 5 are photographs showing reinforcing in place. Figure 1 is a general view at the junction of the roof and shell including one rafter, and illustrates the manner in which the reinforcing is joined together at the various points. This photograph was taken at a weakened roof seam along the edge of a safety section, and shows how the reinforcing is cut. Figure 2 is another view taken at the junction of the roof and shell along a line of a weakened seam, and more clearly illustrates the method of cutting the reinforcing. Figure 3 is a photograph taken at the center of a roof, and clearly illustrates the application of the reinforcing to the rafters and roof sheets. Figures 4 and 5 illustrate the application of the reinforcing to columns, girders, braces, and rafters. Figures 6, 7, and 8 are photographs taken during the application of the reinforcing to the roof of a 60-foot-diameter tank. Figure 6 is a closeup view showing the application of the rods to a small section of the roof, whereas Figure 7 is a more general view showing the rods in place over a larger area. Figure 8 is a photograph taken after the mesh has been applied to the rafters and roof sheets.

For new tanks, it has been found more expedient to install the reinforcing steel on the roof section during the construction rather than after the tank has been erected completely. The method of installing steel reinforcement on new construction is illustrated in Figure 4 (Kelly). Before placing the roof sheets, the rafters are completely wrapped with the steel mesh in the same manner as previously described for girders in old tanks. Steel mesh then is stretched between the rafters to form a mesh roof over the entire roof area; ¼-inch reinforcing rods are tackwelded to the roof sheets before they are put in place, and conform to the pattern described previously for old tanks. After the roof plates with rods attached have been erected, the previously installed mesh is tied to the rods. Figure 9 is a photograph showing this type of installation.

The mix for the gunite lining consists of one part of cement to three parts by volume of sand. Clean, washed sand, with a nominal moisture content conforming to ASTM Specification C-33-39 for fine aggregates, is used. A standard brand of portland cement conforming to ASTM Specification C-150-40, type I, is used. The cement and sand are mixed thoroughly, and then sifted on a ½-inch-mesh screen. A type N-1 cement gun is used for applying the gunite lining. It is applied to a 1-inch minimum thickness on the shell, roof, and structural members, and to a 2-inch minimum thickness on the bottom. When applied to thin roof sheets of old tanks, it may be necessary to apply the gunite in several coats, allowing the gunite to set up slightly between each coat to prevent excessive sagging and resultant cracking of the gunite.

The sequence of applying the gunite is from the tank top to the bottom. The under side of the roof, rafters, girders, and upper 5 feet of the columns and shell are sandblasted. Reinforcing steel is installed, and the gunite applied. When the girder tops cannot be gunited, concrete is placed by hand. The ¼-inch vertical reinforcing bars for the shell need not be installed in 5-foot lengths, but may be cut long enough to extend from the tank top to the bottom. They can be tackwelded at the top of the shell, and

left hanging loose until subsequent strips of lining are installed.

The sandblasting, installation of reinforcing, and guniting can be done most conveniently from a raft consisting of a wooden platform built over several airtight drums to give sufficient buoyancy. Such a platform usually is built in the shape of an oblique parallelogram, so that a larger portion of the raft may be placed contiguous to the tank shell. The size of the raft should be governed by the diameter of the tank; but, in general, should be small enough to maneuver between the columns and sufficiently large to be moored easily between columns or between column and shell. After the roof and upper 5 feet of the shell have been completed, water is drawn from the tank until a working level is reached—which would permit the application of another 5-foot strip of lining to the shell and columns. This operation is repeated until the entire shell has been covered. Figure 10 to 26, inclusive, are photographs showing the guniting in various stages of application, and require no explanation.

After completion of the guniting operation, all surplus material should be removed from the tank.

**FIGURE 23**
**Closeup view of gunite applied to roof at junction of shell.**

The lining is cured by being kept moist for a minimum of 48 hours before the tank is returned to service. During cold weather it may be necessary to place moist steam in the tank in order to maintain a temperature high enough for effective curing in a 48-hour period. In mild climates this added precaution usually is unnecessary. The curing assures uniform hydration, prevents excessive shrinkage and surface cracking, and results in a stronger and more durable lining. The lining is given a final inspection before going into service to determine whether there are any defects in the guniting.

Humble Oil & Refining Company reports that its costs per square foot for the installation of gunite linings at its Baytown refinery is 40 cents for the roof and structural members, 37½ cents for the shell, and 35 cents for the bottom. These costs are between 50 and 60 percent of the cost of a new steel tank. This company claims that gunite linings easily can be justified economically due to the fact that they may be applied to a tank in such a corroded condition that replacement is the only alternative. This company reports that the gunite linings in the tanks at its Baytown refinery have not been installed long enough to determine their maximum effective service

**FIGURE 24**
**Another closeup view of gunite applied to roof at junction of shell.**

**FIGURE 25**
**General view of interior of tank roof with gunite partly applied.**

**FIGURE 26**
**Gunite and reinforcing partly applied to shell of tank.**

life, but its experience to date indicates that such linings should prove satisfactory and economical for the protection of steel storage tanks against the corrosive agents in sour stocks.

Standard Oil Company of New Jersey was troubled with the formation of iron sulfide on the walls of floating-roof tanks in which untreated West Texas heavy naphtha was being stored. In order to prevent the formation of iron sulfide and to prevent corrosion, this company tried gunite-coating all-exposed surfaces in these tanks. Because clearances were small, the thickness of any such gunite coating had to be kept to a minimum, and this made it impracticable to use any reinforcing. The gunite lining was applied to the entire shell and to the side of the floating roof, which, in most cases, was of the pan type. The surfaces to be gunited were well sandblasted with coarse sand prior to the application of the lining. The mixture used was one part of portland cement to two parts of sand. The gunite was applied without troweling to a thickness of ½ inch, or slightly less, in one coat. The work was done by using the floating roof as a scaffold, the guniting being started at the top and carried down as the roof was lowered by withdrawal of water until the roof rested on the bottom of the tank. Later the roof was floated up and supported on its legs off the bottom of the tank to permit guniting of the lower portion of the tank which had been covered by the floating roof. The sides of the floating roof were coated by floating it to the highest level possible and by coating all exposed surfaces. Most of the tanks used in this service were equipped with the Haupt-type seal, and any roughness on the surface had little effect on the seal. When Wiggins-type seals are used, it is necessary to trowel to a smooth surface to prevent abrasion and wearing of the seals.

The only precautions taken were to have the surfaces well sandblasted and not to apply the gunite during too cold weather. Of a number of installations, only one has given any serious trouble or required any major repairs, and that was applied when the weather was practically at the freezing point. One such lining was installed in a 60-foot x 34-foot 8-inch working tank in November, 1931. Minor repairs were made by reguniting small broken patches in July, 1933, the spring of 1934, August, 1937, July, 1938, and September 1940. This tank was recently out of service, and the guniting was found to be intact with no repairs required. Another lining was installed in a 115-foot x 35-foot tank in July, 1935, and minor repairs have been made 3 times since then. In another tank of the same size, the lining was installed in April, 1936, and minor repairs have been made twice. The records of repairs to other tanks are similar. None of the linings to date have been renewed completely.

It appears, from the experiences cited and from information available concerning other installations, that gunite protection of storage tanks is the most feasible means of preventing corrosion and maintaining tanks for the duration of the emergency.

# Appendix I

E. S. DIXON, The Texas Company

MANY leased tanks in the producing fields have been built of galvanized-steel construction, and one running tank in a refinery with a galvanized wrought-iron roof.

Galvanized roofs are being used in various fields; and in most cases those roofs are much better than plain steel. There have been some instances when galvanized roofs were reported as unsatisfactory; but, in general, for stock tanks, galvanized roofs are successful; and in some cases the base metal is wrought iron instead of steel. The weight of the zinc coating is an important item for rigid specifications. Usually 2 ounces of zinc per square foot is specified, but it would be wise to ask for 3 ounces of zinc per square foot when zinc is available. Some refiners use galvanized roofs quite extensively, these having been in service for a considerable period of time with satisfactory results.

A producing-department report describes a test on a 300-barrel galvanized wrought-iron gun-barrel tank. Original installation is not on record. Inspection of the outside in June, 1937, indicated the tank in good condition; however, inspection in January, 1938, showed nuts and bolts rusting and causing small leaks. In June, 1938, there was a hole in the bottom ring; inspection, December 1, 1938, showed 32 holes in the bottom ring, with more expected in the future. The conclusions of this company were to the effect that this was unsatisfactory for use as a gun-barrel tank.

In another field records were shown of galvanized lease tanks with 50 to 60 months' service, which tanks are still in good condition. Bolts used with these tanks also are galvanized. The cost of galvanized over plain steel is given as $75 for a 250-barrel tank.

Galvanized stock tanks are used in another field, and records for these are as follows: 50 months, 51 months, 44 months—and still in good condition. There is some rusting on the outside; but, in general, the tanks are in good condition.

An inspection was made of galvanized stock tanks located in another field. They had galvanized stairs and galvanized walkways, and are in excellent condition although 50 months old. These are bolted tanks. Some of the bolts were rusty; however, they have been painted, and are in excellent condition. Examination of tanks just inside show bright zinc coating under a slime-like deposit. It is estimated that these tanks will last five years more at least.

Located in still another field is a 500-barrel tank of galvanized iron, with 12-gage sides and bottom and 14-gage aluminum roofs and rafters, which tank was erected in July, 1923. It was in excellent condition, with no corrosion present, and still is in service in 1941.

In another field a galvanized wrought-iron bottom and roof were installed in one tank, which the operator believes may be responsible for its good record. The cost per tank may be $150 extra for the wrought-iron roof and bottom.

Two tanks with galvanized wrought-iron roofs in

still another field have been reported as unsatisfactory and not recommended. They contain very sour crude and very sour gas.

Tanks with galvanized tops and bottoms are being tried in another field; galvanizing costs are claimed to be one third more than steel.

A refinery rundown tank was constructed with a galvanized wrought-iron roof with aluminum rivets and galvanized rafters and center poles. This tank was installed, in March, 1935, for corrosive service. Adjacent to this tank is a companion tank, with roof installed the same date for the same service. The roof of this companion tank, which is of plain steel, was replaced in 1941. Inspection of the tank with the galvanized wrought-iron roof in 1941 showed it to be in very good condition except for a few small holes. This tank was installed as a straight-run kerosine rundown tank, and the latest inspection was made in August, 1942. At that time the life of the tank was 7 years, and most of the galvanizing was intact; however, the character of its coating had changed, and was more in the nature of a paint; and it was assumed that the zinc had been changed to zinc sulfide or zinc oxide. There were about 25 places where holes had come through the roof, and repairs had been made by the use of bolts and patching. There was one leak along the seam about 4 feet in length and 12 inches in width which had been patched extensively. The aluminum rivets were in excellent condition. The center post had been galvanized; and that portion of the post in the vapor space still maintained the zinc coating, whereas that portion in the liquid in the tank was corroded badly. Sixty percent of the zinc on the galvanized rafters was gone, and some of the rafters were rusted quite badly. When one walks on the roof of the tank, one experiences the fact that the roof is solid and that there is no thinning to be detected.

One item of interest reported by operators is that much less rust and products of corrosion fall to the bottom of the tank. This problem frequently is the cause of pits in the bottom of the tank; and, if such is the case, there is an absence of pitting usually experienced in the plain steel roofs. The ease of cleaning is to the advantage of the galvanized roof, and greatly offsets its original increase in cost.

We predict the life of this roof as being at least twice that of the plain steel roof when the proper minor repairs are made from time to time.

The 3/16-inch wrought-iron roof plates, steel rafters, and center support were hot-dipped after shop fabrication. Aluminum rivets were used in assembly. The cost of this construction could be reduced by using galvanized steel instead of wrought-iron plate, and by making economies in fabrication and erection, so that it should not be more than 40 percent higher than the cost of regulation tanks on future work.

Savings result not only from a life about double that of a plain steel roof, but also from reduced cleaning costs due to less deposits as compared to those on plain steel roofs, and to elimination of exterior roof painting.

### Aluminum Foil

Considerable work has been done with regard to protection of the outside of roofs and tanks using aluminum foil 0.004 inch thick. In one case the foil was applied with asphalt adhesive, whereas in another instance roofing felt sealed with hot asphalt was used. Corrosion showed up within a short time, and the tanks subsequently were reported as failures due to refinery and salt vapors.

Our pipe-line company installed aluminum foil on tanks subject to atmospheric corrosion. One tank, on which 0.002-inch aluminum foil had been applied, showed no corrosion or pitting after 5 years. Difficulty was experienced, however, with rust spots occurring beneath the foil where water stood on the roof. Adhesive on roof foil lost practically all value on 50 percent of the surface, and repairs were unwarranted.

The same conditions mentioned above were experienced when 0.003-inch foil was used on another tank roof.

Another tank was equipped with 0.004-inch foil and a heavy coating of hot asphalt as adhesive. Inspection revealed that this tank was in good condition after four years' service.

Reports indicate that cold adhesive is not satisfactory, but hot application shows good results if the tanks have not been sprayed.

Saving of evaporation losses through the use of aluminum foil has been negligible and the cost high; and, as a result of these tests, we have concluded that no further experimental work should be conducted with aluminum foil.

### Aluminum Roofs

At one refinery we installed aluminum roofs on 2 tanks in 1937. They were 42-foot x 15-foot 3700-barrel tanks. These roofs were riveted with aluminum rivets, because it was felt they could not be welded satisfactorily; however, we learned that other refineries have used welded aluminum roofs successfully.

We have experienced some difficulty in properly caulking the edges. We used ⅛-inch-thick aluminum sheets and outside rafters; and, at the present time, they have given satisfactory service in sour-oil service.

Our producing department has several aluminum roofs in service; and in one district we have records of long life with aluminum roofs and rafters; however, the cost is claimed to be excessive. We have information to the effect that aluminum roofs cost twice as much as steel roofs, but there is no information available on the cost of aluminum rafters. It is felt, however, that when aluminum becomes more available after the present emergency, it should be considered for tank roofs.

Another lease tank has a 14-gage aluminum roof. It was erected in 1932; was in excellent condition, and still was in service in 1941. A 500-barrel gun-barrel tank located in another field was constructed with steel shell and aluminum roof. This tank was in excellent condition in 1941. Also a stock tank—a high 500-barrel steel bolted tank, with aluminum roof, rafters, and bolts on the roof—was in excellent condition when inspected in 1941, and had been in service since 1935.

### Lead Foil

We have on record experimental work done with lead foil as a coating for roofs where corrosion is a factor, but the results were not entirely satisfactory. Part of the failure was due to the adhesive and, also, because of the fact that lead foil is very thin and can stand no mechanical exposure. It is felt that lead foil is not successful if the material is subjected to any type of mechanical wear; also the adhesive has certain definite limitations. However, our company has

felt that the question of lead foil should be followed, as it is developed by other companies.

### Paint for Under Side of Tank Roofs

We have found no coating in the nature of paint which has shown satisfactory or economical results on the interior of running tanks.

In the producing department the under side of roofs, vapor space, and bottoms of lease and storage tanks presents the severe problem of corrosion. This is also true in the pipe-line department, and the use of paint and coatings has been investigated over a period of many years. Among those tested are various asphalt and coal-tar coatings. In many cases tanks are protected by various coatings. Service records vary with respect to the merits of these coatings. The success of coatings depends upon the care exercised in preparing the surface, as well as the skill of the workmen applying the coatings. Application of these coatings usually is done by outside contract rather than by common labor or our own organization—which adds to the cost.

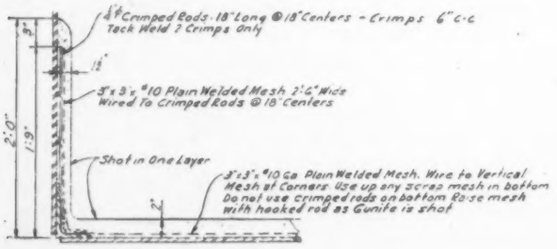
A production tank was coated inside with neoprene; i.e., the under side of roof, shell, rafters, and roof supports of a low 250-barrel tank handling sour crude; the tank was put in service in November, 1938. It was reported as satisfactory in 1941. This is a three-coat job brushed on, the surface having been sandblasted prior to coating. Neoprene is not now available.

### Gunite

Gunite linings have been used in tank bottoms for more than five years at refineries, with very satisfactory results to date. Details of these linings are shown in Figure 1 (Dixon).

In California numerous tank bottoms have been lined both in the crude and pressure-still areas. The latest inspections have revealed these linings to be in very good condition. No further leakage has developed in any tank bottoms that have been so lined. Gunite-lined bottoms in other refineries are an established practice.

Two refineries reported early failures of neat-cement wash and thin gunite roof linings. The wash, applied to the under side of three roofs by means of a spray gun, was gone after six months' service, except along seams and around manways and hatches. A ¼-inch-thick unreinforced lining on a roof and rafters at Los Angeles was about gone, except around the crown sheet, after 5½ months' service.


Crimped Rods 18" Long @ 18" Centers - Crimps 6" c-c
Tack Weld 2 Crimps Only
18"
3" x 3" x #10 Plain Welded Mesh 2'-6" Wide
Wired to Crimped Rods @ 18" Centers
2'-0"
1'-9"
Shot in One Layer
3" x 3" x #10 Ga. Plain Welded Mesh. Wire to Vertical
Mesh at Corners. Use up any scrap mesh in bottom
Do not use Crimped rods on bottom Raise mesh
with hooked rod as Gunite is shot
2"

*Notes*

Sandblast all surfaces to be gunited free from oil, dirt, and scale.

Make gunite at least 1 inch thick over all rivet heads.

Wrap all posts with mesh to same height as shell.

Wood-block swing-pipe supports to be removed and replaced on top of gunite.

Steel supports to remain in place, and gunite shot to 2 inches thick against them.

CURE—After final set of gunite, spray daily for three days.

GUNITE—Mix 1 part portland cement to 2½ parts of clean, coarse, sharp sand.

All pipe connections to be extended through lining with nipples.

**FIGURE 1 (DIXON)**
**Method of guniting tank bottoms.**

On the other hand, the ¼-inch unreinforced gunite lining on the shell and center column of this tank, and on one third of the top ring of another tank, was in good condition, the latter after 16 months' service. But ½-inch-thick and ¾-inch-thick unreinforced top-ring sections showed considerable cracking, the heavier coating being in the poorer condition.

It might be of interest to mention that an unreinforced gunite lining was applied to the shell and under side of the roof and rafters of one distillate-running tank 35 feet in diameter by 12 feet high during December, 1939. This gunite was applied ¼-inch thick. Inspection made on July 9, 1941, revealed the roof coating had failed completely, but shell lining was in excellent condition except for vertical crack along one seam in top ring.

Also in January, 1939, the top ring of a 40-foot-diameter by 12-foot-high running tank was covered with unreinforced gunite of varying thicknesses. One third of the circumference was gunited ¼-inch thick; one third, ½-inch thick; and balance, ¾-inch thick.

The bottom ring of this tank was given a brush coat of neat cement.

Inspection on July 9, 1941, indicated the one third section of top ring with ¼-inch coating to be in excellent condition; slight cracks had developed in section ½-inch in thickness, whereas large cracks existed in the one third section ¾-inch thick. The brush coat showed approximately 75 percent failure.

In the producing department there are certain fields which have tanks in service, the interior of which are protected by gunite. These tanks are very successful. The frequency with which tanks are moved from one location to the other prevents the extensive use of gunite except when the tank will be in service for a long period of time.

It has been decided that no unreinforced gunite roof linings should be installed; unreinforced gunite linings for shells ½-inch thick and heavier are unsatisfactory, and should not be used; linings about ¼-inch thick of unreinforced gunite appear to have merit for shell protection of tanks not more than 12 feet high; but available data are insufficient to draw final conclusions, and additional test installations should be made. Finally, reinforced gunite is the most satisfactory protection for roofs. Shells more than 12 feet high also should be protected with reinforced gunite.

The gunite protection now seems adapted to our requirements, as it can be used not only with new construction, but should be applicable, with some reinforcing rods below present rafter flanges, on existing roofs which are becoming thin—provided the metal is cleaned thoroughly. Protection of existing roofs before they become so deteriorated that they will not hold gunite, even though reinforced, should be the practice, and an examination of roofs of tanks in the more corrosive services should be made with this in view by all plants experiencing relatively rapid deterioration of roofs.

### Roofs with Structural Members on the Inside

The use of inside-rafter construction on larger tanks would seem best from the standpoint of initial cost and maintenance, and also strength. This conclusion is predicated on the theory that the gunite will give satisfactory protection, with minor repairs, for

many years, and is consistent with the policy of guniting existing inside rafter roofs.

### Roofs with Structural Members on the Outside

For running tanks, where our most corrosive conditions are encountered, the higher cost for outside-rafter construction should not be necessary, and greater strength is not needed. The outside-rafter construction, then, should be preferred generally on new work.

A number of tanks with roofs having structural members on the outside have proved satisfactory. The increase in the number of tanks so constructed depends upon the rate of corrosion and the increased cost for this type of construction; consequently, this problem is chiefly one of economics.

### Protection by Oil

In some fields and pipe-line tanks we protect the rafters and under side of the roof by raising the oil level to such a height that rafters and under side of roof are flushed with oil twice a month. We consider that flushing with oil gives a protective oil coating which retards corrosion, as corrosion usually takes place in the vapor space of tanks. Another company sprays the under side of roof and rafters with oil, using spray nozzles.

### Use of Neutralizer

At one refinery the most severe corrosion experienced is in tank roofs where raw pressure gasoline or raw straight-run gasoline is stored. Experience shows that about five to six years' service is given by a pressure gasoline roof, and from six to seven years' by a straight-run gasoline roof. In both cases large amounts of elementary sulphur are noted—which is, no doubt, one of the factors causing the rapid deterioration. There has been some corrosion to the bottoms of tanks in which pressure gasoline was stored. This was caused by aqueous solution of hydrogen sulfide, and this condition was corrected by pumping spent caustic into the bottoms of these tanks; therefore, this matter is no longer a problem.

In most respects the stocks handled at this refinery are non-corrosive, and the tank repair costs are not a major operating item.

### Cathodic Protection

The following is our experience with cathodic protection, as of the year 1938:

A brief description was given of the theory of cathodic protection of tankage and lines. Information was presented in detail on the methods used in protection of tankage at one terminal. A report, amplified to include much of the information on various points requested, follows:

"During the past 50 years, a number of theories of corrosion have been advanced, most of which have some basis in fact. However, until the electrochemical theory was recognized, none of the older ones was completely adequate.

"In order that corrosion of iron as usually encountered may proceed, two conditions must exist:

"(1) There must be moisture present, and

"(2) The iron must be ionized, or enter solution in an active state. (The word 'iron' is used in the generic sense here.)

"As soon as iron is placed in contact with water, it immediately begins to displace some of the hydrogen ions present. This reaction is fundamental for all cases of underground corrosion, and leaves both the iron ions and hydrogen atoms free to combine with any other substance. From this point the reactions that follow are entirely dependent upon the environment. Herein lies the essential difference between the various types of corrosion; i.e., after the iron has dissolved or ionized, it may form any one of a multitude of end products, or a mixture of several. Usually, both ferrous and ferric hydroxide are found on the surface of the corroding metal. The ferric hydroxide is better known as ordinary rust, while the ferrous compound is of a dark, greenish-black appearance. It is found adjacent to the metallic surface, and is readily oxidized to rust upon exposure to air.

"The important point to be remembered from the foregoing is that, in all ordinary cases of underground corrosion, the primary reaction is the same. Furthermore, this reaction is of an electrical nature, by which statement is meant that as soon as a metal is placed in a solution, a measurable voltage appears between the metal and the liquid. It is this voltage or solution potential that is responsible for the initial step in a corrosion process. Therefore, if we are able to oppose the voltage, we shall have solved our corrosion problem. This is exactly what is done when cathodic protection is applied.

"To understand better the mechanism of cathodic protection, consider a simple electroplating cell, which is made up of two electrodes suspended in a conducting solution. A direct current is passed between the electrodes, the one by which the current enters the solution being called the anode, and the other the cathode. When the current leaves the anode, it carries with it some of the metal in a dissolved or ionized state and deposits it on the cathode. This action is entirely analogous to the corrosion taking place on a tank bottom in contact with soil. The corroding structure is the anode, the soil is the cathode, and the soil moisture the conducting solution or electrolyte. The direct current responsible for corrosion may have any of a multitude of sources, such as stray currents from d.c.-operated traction systems, dissimilar metals, variations in soil moisture and composition, earth's magnetic field, etc. Regardless of the origin of the current, wherever it is discharged to the earth, it corrodes the structure in proportion to its intensity and duration of flow.

"It is apparent that if the direction of the current flow be reversed, corrosion will cease, i.e., if the pipe is made the cathode. In practice, this is accomplished by connecting the positive terminal of a d.c. generator to a ground bed, which is made up of a mass of junk iron. The negative side is attached to the line to be protected. When the generator is operating, the current flows from the positive terminal to the ground bed, through the earth to the pipe and back to the generator by way of the negative return. The voltage is of sufficient intensity so that it not only opposes the solution potential originally existing, but actually causes an appreciable flow of current from the soil to the pipe, thus inhibiting completely any tendency of the structure to corrode.

"The question has often been raised as to whether or not the application of cathodic protection damages the coating on an underground structure. Undoubtedly, even the low protective voltages commonly employed have a tendency to break down the coating, particularly after moisture has penetrated to the structure. But by the same reasoning, wherever moisture has penetrated or wherever there is a path for the current to reach the structure, there is equal

opportunity for current to leave or for corrosion to take place, and this is exactly what we are attempting to prevent. Therefore, it would seem only logical that the merits of cathodic protection far outweigh the ill effects caused by it.

"It is worthwhile to note that in most instances the total corrosion is made up of two distinct parts:

"(1) That which exists by virtue of the tendency of any metal to enter solution in proportion to its corrosion potential, and

"(2) That part which is caused by some external source of direct current as mentioned above.

"In either case, the effect on the structure is the same for any given current value, and the corrosion is the result fundamentally of a current discharge. Hence, cathodic protection applies equally well to both types.

"It is necessary to be able to determine corrosive areas or 'hot spots' without waiting for leaks to appear in the tanks. The simplest and most dependable method so far developed is that of current measurements on the lines connected to the tanks. From an inspection of the data obtained, it will be apparent whether there is an accumulation or a discharge of current. The actual measurements are made by observing the potential drop along a known distance of pipe. Knowing the weight of pipe in pounds per foot and the specific electrical resistance, the current flow is readily calculated.

"When the 'hot spots' have been located, the next step is to find out just how much direct current will be needed to protect any given section or area. This is best done through the expediency of a portable electric welding machine or similar engine-driven direct-current generator. The current output is adjusted to give the desired field of protection, which field is measured by means of a sensitive voltmeter. These voltages are taken between the structure and the earth, and are a direct indication of whether the structure is anodic or cathodic, and to what extent.

"Knowing how much protective current will be required for a given location, a cathodic unit of the proper size may be recommended for the permanent installation. The term 'cathodic unit' is applied to all types of equipment used to supply direct current for cathodic protection. This includes motor-generator sets, rectifiers, engine-generator sets, and windmill generators.

"First cost of an installation obviously depends upon the current requirements. It may range from as little as $300 to as much as $1500. On the average, it will be close to $1000.

"Where electrically-driven generators are employed, purchased power will cost about $35 a month for the average unit. In some instances, it is possible to install the units at a pump station where sufficient electrical power is available at practically no cost.

"There are, of course, a great many locations where no electrical power is available at any reasonable investment. Here the windmill finds its application. What the windmill saves in operating costs, it more than loses due to its intermittent running. However, it affords a fair degree of protection, and is certainly better than no unit at all.

"Maintenance on the various cathodic units has been low considering that many of the locations are inaccessible and the units are not regularly inspected. Fortunately, small electrical machinery requires very little lubrication.

"Cathodic protection is by far the most economical system of maintaining tank bottoms in first-class condition. Considering cost of $35 a month and a maintenance of $50 a year, all of which values are typical; assume a range of protection of five miles as an average. Then the total cost of protection, including depreciation, will be in the neighborhood of $114 per mile per year. This figure speaks for itself when compared with the usual maintenance costs encountered in pipe-line operation where frequent repairs and occasional reconditioning are standard practice.

"So far, only generalities have been discussed. To see how an installation works out in practice, let us turn to one terminal where there are located 14 tanks. These are all interconnected by a number of lines, the principal one being a 24-inch suction running the entire length of the tank farm and tied in to each of the tanks.

"The cathodic unit, which is a motor-generator set capable of draining 150 amperes, was originally installed to protect the several main lines entering the terminal. Since that time, several new tanks have been built, and the necessity for protecting the tank bottoms arose. However, all the tank lines are either Dresser- or Victaulic-coupled, and both types offer considerable resistance to the flow of electric currents. It was, therefore, necessary to bond across each coupling in the tank farm with a short piece of heavy copper wire. This allowed adequate electrical drainage of the facilities.

"It is important to be able to determine readily the field of protection as well as the distribution of current where several companies are involved. The degree of protection is measured with a sensitive voltmeter and non-polarizing type of electrode for making contact to the earth. When the voltmeter is connected between the structure to be tested and the earth, it will indicate whether the structure is negative or positive to the soil. As mentioned earlier in the discussion in connection with the practical application of cathodic protection, it is not only necessary to oppose the solution potential of the metal, but actually it is required to force sufficient current from the soil to the structure so as to make the latter appreciably negative. This will inhibit any tendency toward corrosion and, hence, the corrosion itself. It, therefore, becomes a simple matter to determine the field of protection of a cathodic unit by measuring the voltage between the structure and the soil at various points. Wherever the potential is less than a quarter volt negative, there will be a small amount of corrosion taking place, although it will not become serious until the structure is actually positive to the surrounding medium.

"Because of the construction of the electrode used in making the potential measurements, the voltmeter will not indicate directly the actual condition existing. Instead, a correction factor of 0.55 volt must be applied to all readings. If the reading is greater than 0.55 volt, then the structure is negative to the soil by an amount equal to the difference; if the reading be less than 0.55 volt, then the structure is positive by an amount equal to the difference. However, it is cutomary to show the readings uncorrected. Thus, for example, if a voltage of 0.75 volt is shown, the actual condition is 0.75—0.55, or 0.20 volt negative is necessary to insure complete protection against corrosion. This would mean a reading of 0.80 volt uncorrected.

"Referring back to the above-mentioned terminal, since the installation was first made over a year ago, the erection of the several new tanks built and tied

in to the original system reduced the protection level generally, but all the structures are still decidedly negative-to-ground, so that probably only 2 or 3 percent of the original corrosion rate still attains. This can be readily corrected by increasing the output of the cathodic unit through a lowering of the circuit resistance.

"Where there are facilities of several companies interconnected, it is desirable to know what percentage of the protection is attributable to each. This, too, is easily determined by measuring the current flow on the various lines and distributing the operating cost in proportion to the amperes drained.

"In contrast to the foregoing are the installations along a trunk line. One of the best examples about which we have considerable information is a 12-inch main line in Southeast Texas. This section traverses some of the most corrosive natural soil in the entire country, based on Bureau of Standards publications of their findings in soil-corrosion studies. The line is approximately 33 miles long, and the majority of the line is lying in either rice fields or marshes. Since the line was laid, there have been numerous corrosion leaks, particularly on the south end near the refinery. The leaks, together with the results of the test-coupon survey, made some kind of protection imperative. These test coupons deserve our attention for a few minutes.

"At frequent intervals along the line, usually 1500 feet to 2000 feet as an average, were buried a pair of steel plates about 6 inches long by 1½ inches wide by ¼ inch thick. They had been cut from a section of ordinary line pipe so that the composition would not differ greatly from that of the main line. Prior to their burial, they had been carefully cleaned and weighed to the nearest 0.01 of a gram, which amounted to better than 0.01 of 1 percent accuracy. Then at each test location one coupon was buried unattached. The latter were to serve as an index to the corrosiveness of the soil locally, while the former would reveal the electrolytic condition existing on the pipe surface.

"After a burial period of 16 months, the coupons were dug up, cleaned, and reweighed. The results were, to say the least, indicative that something had to be done. In some locations the attached coupons had lost as much as 44 percent of their original weight, and the overall average was close to 20 percent. Even some of the unattached coupons lost nearly 4 percent, which is appreciable for a small isolated structure in saturated soil.

"Accordingly, a series of temporary tests were made with a portable generator to determine the best locations for permanent units as well as the current requirements. It was finally decided to install 4 motor-driven generators, each with a capacity of 80 amperes. The first was 2 miles from the southern terminus; the second, 6 miles; the third, 16 miles; and the fourth, 22 miles. When all of the units were operating, a complete resurvey was made to see whether the units were effective. The results were encouraging; better than 7 miles' protection per unit was average. Only 4 miles on the north end were not entirely protected, and this section lay in comparatively dry, sandy soil.

"In order that we might be absolutely sure of the effectiveness of the units in preventing corrosion, it was decided to bury a new set of coupons. This was done in exactly the same way as the first set, and in precisely the same location. After a period of 8 months, they were dug up and reweighed. There was no doubt whatsoever of the merits of cathodic protection when the second set of coupons was compared with the first, and the loss in weight of the attached coupons in the second set confirmed the potential readings observed after the units were operating. Where a negative voltage of a quarter volt or more was read, there was no loss in weight of the attached coupons; but where the reading was less than a quarter volt negative, there was a noticeable loss in weight, which increased as the protection decreased.

"This test-coupon survey described seems to be one of the most tangible pieces of evidence yet brought forth that cathodic protection is all and more than claimed to be as a preventive of underground and underwater corrosion. The two sets of coupons are prime examples of a 'before' and 'after' remedy, a remedy that approaches a 'cure-all' for external corrosion of pipe lines and tank bottoms.

"In conclusion, a word about the technique of electrolysis surveys and the economy of cathodic protection: During the five years we have been engaged in this work, we have developed a procedure that is simple and rapid, yet effective. It consists of making current measurements on all the lines involved to see where the corrosion is localized and, also, whether there is some artificial and easily corrected source of direct current causing the electrolysis. Sometimes the mere installation of an insulating flange will alleviate the condition. If cathodic protection appears to be the only solution, then a temporary test is run as described elsewhere. This test will show just how much current will be required from a permanent unit, from which can be accurately predicted the investment as well as the monthly operating cost. It is seldom that these figures will be prohibitive when compared with the cost of reconditioning at intervals. Cathodic protection offers permanent relief from corrosion; reconditioning, only temporary.

"Cathodic protection is not only feasible in most cases, but economical as well, especially where the structures are coated with either asphalt or enamel. In this respect, we are particularly fortunate, since most of our trunk lines were coated at the time of laying. Even in the case of bare structures, cathodic protection appears to be economical where the surface exposed is not too great.

"There is a great field for improvement of both electrolysis testing and cathodic installations, particularly at terminals and refineries where the facilities are concentrated. In light of the success we have already experienced, however, in eliminating corrosion leaks, we believe that a satisfactory method of protection can be worked out."

It was stated that a complete survey of a terminal could be made within 10 days, and that an installation costing $1500 to $2000 would completely protect a small terminal if the survey were to show the installation of cathodic protection was desirable.

In some installations, grounds consisting of junk pipe bonded to the lines have been installed at a moist location some distance from the pipe lines. These serve as the anode instead of the pipe line proper; and, as the current leaves at this point, the junk ground is corroded instead of the pipe line.

The conclusions on this subject are that failures of lines, tanks, and other equipment in or on the ground, or in contact with water from pits originating on the outside, are due to electrolysis in many instances. Tests for current flow from the line at these points will determine if this is the case, and the proper steps

can be taken to eliminate the current flow into the line at other points or superimpose a countercurrent.

Conclusions with respect to cathodic protection were as follows:

During this year such surveys as appeared to be warranted because of corrosion found on lines, tank bottoms, and other equipment at the plants were made. In all cases the completed surveys indicated that cathodic protection was desirable to prevent corrosion which was apparently due to electrolysis.

Cathodic-protection units had been installed at two terminals, but had not been in service sufficiently long to determine from inspections of the equipment whether protection is being obtained. Surveys, however, made after the units had been installed, indicate that the required potentials, that is 0.8 volt, which have been found necessary to give full protection, were secured on practically all of the equipment involved, and that the remaining small percentage of equipment not receiving full protection was given 90 percent protection by more than 0.65 volt.

One refinery reported on the installation of 4 cathodic-protection units early in 1939 to protect the 45 tanks and connecting lines at a tank farm, where repairs to tank bottoms averaged approximately $1250 per tank every 10 years. California gave data on four installations, several of which have been in service a sufficient time to indicate that they are successful, as leaks previously reported at frequent intervals are no longer encountered.

The cost of operation of these cathodic-protection units varies from $4.00 per month on plant lines in California, and $6.00 per month on a tank-farm installation, up to a cost of $20 per month on each of 4 units installed at a refinery tank farm and $25 per month in another location in California. These costs vary with the unit rate charged for current and the size of the cathodic-protection unit. In no case are they excessive when compared with the savings which will be effected through reduced maintenance charges on tankage and lines, if the theoretical results are proved in practice. The cost of operation on a refinery unit is $960 per year, which, with an allowance of $400 for maintenance and depreciation, will total $1360 as compared to the average maintenance cost without protection of $5625 on tankage, and an estimated cost of $1000 or more per year on lines.

The surveys on electrolysis conducted up to 1939 indicated that much of the spotty corrosion encountered on lines, tankage, and other equipment at the plants is due to stray currents which enter the plants through lines, or result from welding operations or other plant activities.

Cathodic units which had been installed over a sufficient period of time showed that protection was given against this electrolytic corrosion, in that the frequent trouble encountered from line leaks no longer occurred. Test specimens which had been installed bore out these conclusions, in that protected specimens showed no corrosion whereas unprotected specimens exhibited severe pitting.

It is essential that plants carefully observe the nature of corrosion which results in leaks in lines, tanks, etc., and try to determine if chemicals or other known agents are the cause. If not, and provided the corrosion is of the spotty type found when electrolysis is present, they should make preliminary tests with their own electrical and engineering forces.

Although only a few installations had been in service long enough to obtain very conclusive information, results to 1940 indicated that cathodic protection of tankage is very effective in eliminating corrosion due to electrolysis.

When tankage is corroding out rapidly, arrangements should be made to have a survey of the plant made. From this information it is possible to determine if the corrosion is due to electrolysis, and whether the cost of the cathodic installation would be justified on the basis of previous repairs to tankage.

The question of the value of cathodic protection is quite debatable, and the following is an abstract from 1942 conclusions by California refineries. The claim is made that cathodic protection is good insurance against corrosion, although definite conclusions are not made.

One refinery states that its experience with cathodic protection on tankage is limited to one 5000-barrel water tank on which this equipment was installed about 60 days ago.

Another location has applied cathodic protection to a limited extent to the bottoms of tanks. To date there have been no leaks in any of he tank bottoms, and we have no real way of measuring its worth for this purpose. It is known, however, that frequent pipe-line leaks were occurring at this location; and since cathodic protection was applied to pipe lines, practically all leaks in the lines have been eliminated. For this reason, it is felt that the cathodic protection on the tank bottoms is advantageous, and is good, cheap insurance.

### Slope of Tank Roof

Some tanks have been erected having roofs of a pitch flatter than the API standard of ¾-inch per foot. Due to moisture accumulating at the seams and depressions, they required frequent painting, which meant high maintenance costs. To prevent this, the slope should be at least ¾-inch per foot.

### Thicker Than Standard Tank Roofs

For all normal services the standard roof thickness of 3/16-inch has proved satisfactory; however, when high rates of corrosion have been experienced, ¼-inch-thick roofs have been used. This practice is, of course, dependent upon the degree of corrosion.

# Appendix II

C. F. KELLY, Humble Oil & Refining Company

## Introduction

FOR a number of years extensive work has been carried on toward the development of corrosion-protection methods for steel storage tanks. The need for such protection has been due primarily to the severe corrosion of sour stocks. Although severe corrosion has been experienced in crude tanks, the greatest need for increased life has been for tanks handling the lighter distillates. In one group of rundown tanks, handling the most corrosive stocks, major repairs have been necessary in less than 2 years and complete replacement after approximately 3½ years. Although the corrosion has been found to be most severe in rundown tanks, particularly the smaller sizes, the frequency of repairs and replacements has been sufficient in tanks of all sizes handling sour stocks to warrant investigations to determine methods of increasing their service life.

## History of Protective Methods

The annual depreciation for any protective method used would have to be less than that of steel and at the same time should have a reasonably short payout. In addition, any method of protection used should be consistently dependable and require minimum maintenance. Experiments were made with various types of internal surface coatings, including several kinds of paints, enamels, and synthetic resins. Of this group, bakelite was found to be the most satisfactory, but it was dependable for only approximately two years. Because of the frequency of repairs required by these coatings and in view of the uncertainty of complete protection, the cost of such installations was found to be impossible to justify.

Different materials were used in the effort to increase the life of the tanks. Aluminum roofs installed on numerous rundown tanks have given satisfactory service with the exception of being difficult to maintain in a vapor-tight condition. Their initial cost was between two and three times as much as steel roofs; and, after several years' experience with them, it became doubtful if they could be justified economically, as the tanks were subject to being transferred to sweet service for a number of years at a time, with a resulting tieup of the added investment in the aluminum roof. Galvanized (both steel and wrought-iron) roofs also were installed, and were found to have a service life approximately equivalent to that of aluminum; however, their initial cost was about the same as for aluminum.

About 12 years ago a decision was made to experiment with concrete as a protection for bottoms of rundown tanks in sour-naphtha service. This protection consisted of pouring a concrete slab on the tank bottom and applying a gunite extension to the lower 18 inches of the shell. The concrete bottom contained no reinforcing steel or expansion joints, and only a limited degree of success was obtained with this type of installation. Linings of this type were placed in several 30-foot-, 45-foot-, and 60-foot-diameter tanks, and in one 117-foot-diameter tank. In general, such linings were satisfactory in tanks under 45 feet in diameter, and gave adequate protection to the steel when excessive cracking and spalling of the concrete did not occur.

After partial success with the concrete and gunite on the tank bottom, the gunite was extended over the entire inner shell area, with varying degrees of success. The shell was cleaned and sandblasted before the application of the gunite, but no reinforcing was employed. As the gunite was held in place solely by the bond between it and the shell, only a very thin coating, approximately ¼-inch in thickness, could be applied. These linings were not dependable; but wherever they did not fail, the steel was protected, and no evidence of corrosion of the gunite was apparent.

The information gathered during the 10-year period, 1930 to 1940, presented conclusive evidence that a concrete lining would protect satisfactory only steel storage tanks from the corrosive attacks of sour stocks, provided a suitable method could be devised for applying the concrete in such a manner that mechanical failures of the concrete would not occur. Our experience, and the experience of others, indicated that a concrete lining meeting the foregoing requirements could be obtained by the installation of adequate reinforcement and by improvement of our technique of application. By this time the technique of installing the reinforcing and applying the gunite had developed to the point where the cost was well below that of replacing the vessel.

During January, 1941, gunite was applied to the shell, roof, rafters, girders, and columns of a 60-foot x 35-foot tank which was in light-naphtha storage service. A concrete bottom, placed in the tank approximately 10½ years previously, was found to be in a serviceable condition; therefore, it was not necessary to gunite this section of the vessel.

The gunite lining in this tank was inspected after having been in service approximately one year, and was found to be in good condition. At the present time gunite linings have been installed either partly or completely in 21 tanks ranging in size from 30 feet x 10 feet to 60 feet x 40 feet, and in one 120-foot x 40-foot tank.

Experience has indicated that the design of the lining and the method of application are very important factors in determining the useful service life of the lining. The first linings installed consisted of approximately 4 inches of regular portland cement poured over the bottom of the tank. The gunite extension on the bottom of the shell was reinforced with a ½-inch diameter steel rod and with 16-gage 2-inch mesh galvanized poultry wire. Approximately 15 inches from the bottom 2-inch x 2-inch x ¼-inch angle clips were riveted or welded to the shell on approximately 3-foot centers. The reinforcing rod was threaded through a hole burned in the outstanding leg of each clip, and the mesh wire was tied to this rod and extended down the shell and approxi-

mately 12 inches along the bottom of the tank, in order to tie the gunite on the shell to the concrete on the bottom. The gunite was "feather-edged" at the top, and tapered to a thickness of approximately 4 inches at the bottom.

### Method of Installation of Gunite Linings—Preparation of Surface

The guniting of a tank may be divided into three different steps, viz.: 1, preparation of the surface; 2, installation of the reinforcement; and, 3, application of the gunite. For the gunite linings installed at Baytown equal consideration is given to each of

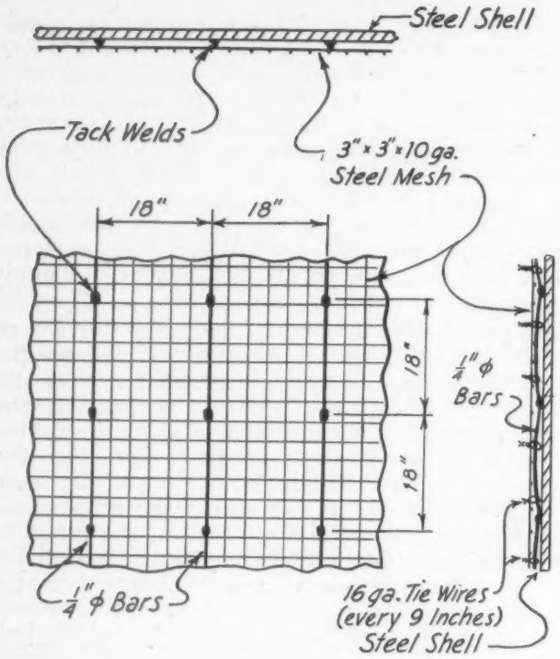



**FIGURE 1 (KELLY)**
**Method of installing steel reinforcement for gunite on shell of tank.**

these three steps. First the tanks are steamed, cleaned, and made gas-free. Then after all dirt, oil, sludge, etc., have been removed, all metal surfaces to be gunited are sandblasted. The sandblasting operation is carried out with an operating air pressure of 100 psi—using a 3/8-inch sandblast nozzle and graded silica sand. All surfaces are sandblasted until there is complete removal of all coke, scale, and foreign material. Even new tanks are sandblasted to bright metal in order to remove the mill scale.

In some instances sufficient time may elapse between the completion of the sandblasting operation and the application of gunite for iron oxide to form on the surfaces. As long as the iron oxide tightly adheres to the base metal, the discoloration of the base metal should not affect the bond between the gunite and the steel. The sandblasting not only assures a good bond between the steel and the gunite, but also serves to clean the steel surface, so that sound welds may be obtained where the reinforcing rods are tackwelded to the tank plates.

### Installation of Reinforcing Steel

The reinforcing on the shell, Figure 1 (Kelly), consists of 1/4-inch-diameter rods placed vertically with a horizontal spacing of 18 inches. These rods are tackwelded to the shell on 18-inch centers vertically, and are sprung away from the sheets approximately 1/8-inch between each weld by means of a claw hammer; 5-foot width of 3-inch x 3-inch x 10-gage steel-wire mesh are tied securely to the vertical rods every 9 inches with 16-gage tie wire. The reinforcing is made discontinuous at the door-sheet joints in order to permit removal in the usual manner, with the addition of breaking the gunite along the seams.

The reinforcement for the tank bottom is comprised of 1/4-inch rods placed on 18-inch centers 2 ways, forming 18-inch squares. The 3-inch x 3-inch x 10-gage steel mesh is laid on the steel bars and tied with 16-gage tie wire at the corners of the squares formed by the 1/4-inch rods. The bars are not fastened to the tank bottom; and, as the gunite is being applied, a helper, working just ahead of the gunite stream, hooks the mesh with a bent rod and pulls the steel mat to the center of the gunite.

The gunite on the under side of the roof is reinforced with 1/4-inch rods tackwelded at 15-inch intervals. A rod is placed on each side and parallel to each rafter, and additional 1/4-inch rods are tackwelded in each bay with a maximum spacing of 15 inches. Pieces of 3-inch x 3-inch x 10-gage steel mesh are fitted into the rafter bays and tied to the

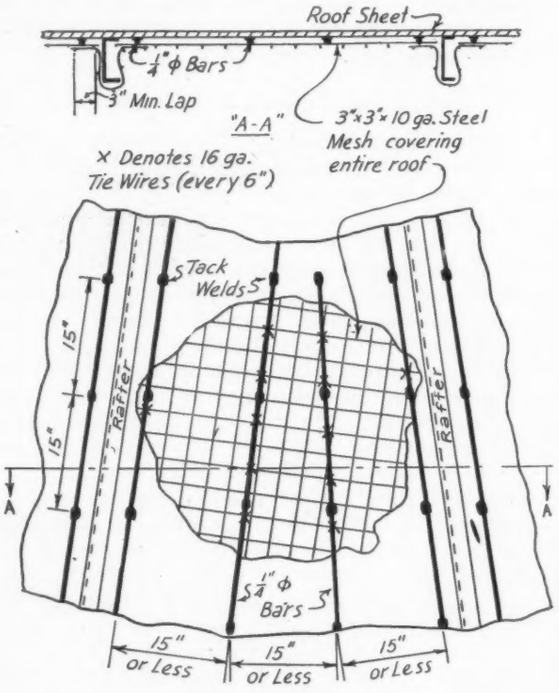



**FIGURE 2 (KELLY)**
**Method of installing steel reinforcement for gunite on roof of tank.**

rods on 6-inch centers with 16-gage tie wire. The rafters are covered with 5-foot-long strips of 3-inch x 3-inch x 10-gage mesh bent to a flanged **U**-shape, with the flange consisting of at least one mesh. These pieces are fitted over the rafters and tied securely to the 1/4-inch reinforcing rods paralleling each rafter, Figure 2 (Kelly). The reinforcement is made discontinuous at the joints for the safety section in the roof in the same manner as for the door sheets in the shell.

The columns and girders are wrapped with 3-inch x 3-inch x 10-gage mesh cut and bent to conform to their respective shapes and securely tied at all joints with 16-gage tie wire. At the junctures of the roof

and shell and the bottom and shell additional mesh is installed in the form of an angle, size approximately 12-inches x 12 inches, and tied to the reinforcing on the top, bottom, and shell as illustrated in Figure 3 (Kelly).

Mesh 5 feet in width has been specified, as it is manufactured in this width and is handled easily.

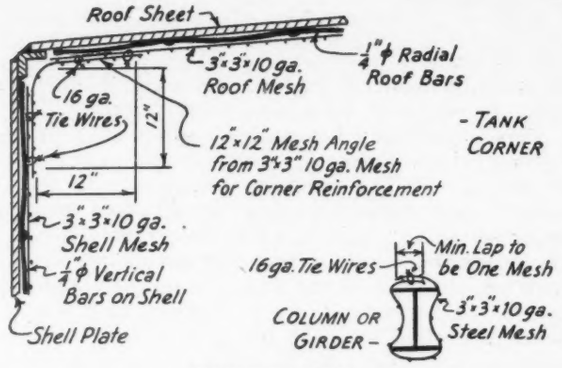

Roof Sheet
1/4" ϕ Radial Roof Bars
3"x3"x10 ga. Roof Mesh
16 ga. Tie Wires
12"
12"x12" Mesh Angle from 3"x3" 10 ga. Mesh for Corner Reinforcement
- TANK CORNER
12"
3"x3"x10 ga. Shell Mesh
1/4" ϕ Vertical Bars on Shell
Shell Plate
16 ga. Tie Wires
Min. Lap to be One Mesh
COLUMN OR GIRDER
3"x3"x10 ga. Steel Mesh

**FIGURE 3 (KELLY)**
**Method of installing steel reinforcement for Tank corners and structral members.**

The wire is lapped one mesh when it is necessary to have a joint.

For new tanks, it has been found more expedient to install the reinforcing steel on the roof section during the process of construction rather than after the tank has been erected completely. The rafters are wrapped completely with the steel mesh, Figure 4 (Kelly), in the same manner as previously described for girders in old tanks. The steel mesh then is stretched between the rafters to form a mesh roof over the entire roof area. The ¼-inch reinforcing rods are tackwelded to the roof sheets while they are lying on the ground, and conform to the pattern as described previously for old tanks. After the roof plates (with rods attached) have been laid in place, the previously installed mesh is tied to the rods on 15-inch centers.

### Application of the Gunite

A gunite lining consisting of one part of cement to three parts by volume of sand is applied over the steel network with a type N-1 cement gun. Clean washed sand, with a nominal moisture content conforming to ASTM Specification C-33-39 for fine aggregates, is used in the mix. A standard brand portland cement conforming to ASTM Specification C-150-40, type I, is used. The cement and sand are mixed thoroughly and sifted on a ½-inch-mesh screen. The gunite is applied to a 1-inch minimum thickness on the shell, roof, and structural members, and to a 2-inch minimum on the bottom. In order to prevent excessive sagging and the resulting cracking of the gunite placed on thin roof sheets of old tanks, it may be necessary to apply the coating in several courses, allowing the gunite to set up slightly between courses.

This work can be done most conveniently from a raft consisting of a wooden platform built over several airtight drums to give it sufficient buoyancy. The platform usually is built in the shape of an oblique parallelogram so that a larger portion of the raft may be placed contiguous to the tank shell. The size of the raft will be governed by the diameter of the tank but, in general, it should be small enough to maneuver between the columns and sufficiently large to be moored easily between columns or column and shell.

The sequence of applying the gunite is from the tank top to the bottom. The under side of the roof, rafters, girders, and upper 5 feet of the columns and shell are sandblasted, reinforcing steel is installed, and then gunite is applied. Where the girder tops cannot be gunited, the concrete is placed by hand. Water then is drawn from the tank until a working level is reached which will permit the application of another 5-foot strip of lining to the shell and columns. This operation is repeated until the entire shell has been covered.

The ¼-inch vertical reinforcing bars for the shell need not be installed in 5-foot lengths, but may be cut long enough to extend from the tank top to the bottom. They are tackwelded at the top of the shell, and are left hanging loose until subsequent strips of lining have been installed.

### Curing of Gunite

All surplus material is removed from the tank after completion of the guniting operation. The lining is cured by being kept moist for a minimum of 48 hours before the tank is returned to service. In some cases

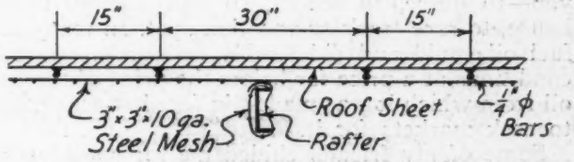



**FIGURE 4 (KELLY)**
**Method of installing steel reinforcement on new construction.**

it may be necessary to place moist steam in the tank in order to maintain a temperature high enough for effective curing in the 48-hour period; however, in mild climates this added precaution is usually unnecessary. The curing assures uniform hydration, prevents excessive shrinkage and surface cracking, and results in a stronger and more durable lining. The lining is given a final inspection before going into service to determine whether there are any defects in the gunite.

### Conclusion

The cost per square foot for the installation of gunite linings at Baytown is 40 cents for the roof and structural members, 37½ cents for the shell, and 35 cents for the bottom. These costs are 50 to 60 percent of the cost of a new steel tank. Gunite linings easily can be justified economically due to the fact that they may be applied to a tank in such a corroded condition that replacement is the only alternative. Although the gunite linings in tanks at Baytown have not been installed long enough to determine their maximum effective service life, our experience to date indicates that such linings should prove satisfactory and economical for the protection of steel storage tanks against the corrosive agents in sour stocks.

# Looking Forward in Refining

BRUCE K. BROWN*
Assistant Deputy Coordinator,
Office of Petroleum Coordinator

SOME weeks ago at Pittsburgh I discussed the problem which the refining industry must meet under the general caption of "Doing More With Less."

More aviation gasoline and less motor gasoline.

More aviation lubes and less civilian motor lubes.

More toluene, more coke, more fuel oil.

Less waste, less crude runs, less skilled personnel.

More safety with less repair-and-maintenance parts available.

More ingenuity to force the maximum war products out of old equipment.

In that talk I made only casual reference to economics and to the retardent effect which unbalanced price ceilings imposed on efforts to reduce gasoline yields and increase fuel-oil yields and coke yields.

Present price ceilings are predicated on a peacetime economy of a year ago when gasoline was the "money crop." Motor gasoline was then avidly absorbed by 27 million civilian automobiles properly shod with rubber tires and rolling merrily hither and yon—to office, to school, to golf course, to road house, to race track or vacation spot. In many areas fuel oil could and did readily sell under peacetime conditions at a price far below the price of the crude oil from which it was made—in fact it was necessary to seek markets for it.

Some of my friends chided me for speaking as I did at Pittsburgh, that is, for calling upon refiners to produce less motor gasoline and more fuel oil without pointing the way by which they might be compensated for the change.

It is unfortunate that refining technology and refining economics do not correlate more closely. In peacetime, when operating under the law of supply and demand, refiners adjusted gasoline yields to fuel-oil yields and adjusted total crude run as well to accommodate their operations to changing market demands and changing prices. That flexibility is gone and cannot possibly return until after peace comes. Neither the present synthetic-rubber program nor any expansion which I can comprehend in the light of the shortage of construction materials can possibly produce enough civilian tries to permit those 27 million automobiles to cavort as in peacetime—even if the cars could be replaced as rapidly as they are wearing out. Nor would the completion of one, two or three pipe lines to the East Coast carry the normal peacetime consumption of gasoline to those areas and at the same time meet war needs.

### Gasoline Must Go Down

The yield of motor gasoline from crude must go down and stay down. It may have to be reduced more in some areas than others but so far as I can see it must go lower in all areas than refiners would like to have it. Thus we have lost what might be called physical flexibility. The rigid demand for more fuel oil and less motor gasoline requires our refineries to turn out more fuel oil and less gasoline in order to properly service the war program.

This inflexibility has nothing to do with prices or ceiling prices. Refineries must simply run that way or not at all. The situation prevailing on the Gulf Coast is only a curtain-raiser—an omen of what must be expected to occur in other locations. Faced with an enormous demand for war products, including fuel oil, and an unnaturally-limited transportation system to more products to market, Gulf Coast refiners have had to make less gasoline, regardless of economics, because the amount of gasoline producible at normal yields is more than can be moved away when preference is given to the movement of fuel oil.

The advent of national gasoline rationing within two weeks will create many situations physically similar to the present Gulf Coast situation, the principal difference being that an unnatural interference with consumption will cause it rather than an unnatural interference with transportation.

A drastic reduction in yield of motor gasoline per unit of crude oil simply must be accomplished. When this task is viewed from the standpoint of any individual refiner, three possible courses of action occur to him:

1. to seek compensatory price adjustments so that he may obtain the same net return per barrel of crude oil after altering his yields;
2. to labor along, turning out products and operating on a lower margin or, quite possibly, in red figures; or
3. to close down unprofitable refineries.

### Refineries Must Operate

However logical such an analysis may be for any one refiner, it is not an answer from the viewpoint of the national economy because most of our refineries simply must continue to run if the war is to be won. How many of the refineries must continue in operation depends, of couse, on the minimum tolerable essential demand for petroleum products. Later I shall present some rough estimates of this demand but for the moment let me merely state that the figures indicate that most of our refineries must operate, whether they operate in the black or in the red.

Since I discussed this topic at Pittsburgh only a few weeks ago, many significant things have happened. Refinery yields have continued to be out of step with realism. National gasoline rationing has turned from a threat to a reality. A Director of Economic Stabilization has been appointed. OPA has held to its position that it will not grant any general elevation of price ceilings on either crude or product, at least in the absence of a type of economic presentation which has not yet been mastered by the industry. And yet the demand for a change in refinery yields is as compelling as before—in fact the fuel oil situation on the East Coast makes it more necessary than ever in Districts 1, 2 and 3, and the crude situa-

* Before American Petroleum Institute, Division of Refining, Chicago, November 12, 1942.

tion on the West Coast makes the move just as desirable in Districts 4 and 5.

### Prices

What appears to be going on is a conflict of an economic policy with a production policy. The abstract logic involved is clear enough. Crude bought at say $1.50 a barrel and turned into fuel oil selling at 85 cents a barrel and gasoline selling at $2.25 a barrel is an operation whose profitability is determined almost entirely by how much fuel oil and how much gasoline is produced per barrel of crude. If refinery yield adjustments are accompanied by compensatory price adjustments the profitability remains the same, but those in charge of price stabilization have refused such adjustment because of its possible inflationary effect. If such price adjustments do not accompany yield adjustments the profitability will certainly be lessened, but a lessened profitability does not necessarily retard production.

But if through failure to make adequate compensatory price adjustments profitability for a particular refining operation disappears, the fuel oil and gasoline will not be produced in that refinery at all, and economic policy will be in violent conflict with production policy.

This war is a war requiring Production, and, if economic policy and production policy are really thrown in violent conflict, product policy must prevail. Production must come first and we must have the essential products which can be produced in our refineries. Further we must have them in as near the correct proportion as refining technology—not refining economics—will let us have them.

While the proprietors and principal executives of refining companies continue to struggle with economics and economists our refineries must go on refining. And during this period the refinery supervisors and refinery technologists must continue with whatever advances in refinery technology can be accomplished to alleviate the economic situation.

In most refineries operating costs are only a small fraction of crude cost but they must be shaved still further. Product losses of any sort contribute nothing helpful to the situation and should be reduced. Finally no permanent cure for the economic losses incurred by revision of refinery yields can be achieved until proprietors, principal executives, economists, and governmental agencies know the basic facts (which only you can give them) as to the ultimate low yield of motor gasoline which can be obtained and the ultimate high yield of war products which can be obtained—regardless of orthodox economic considerations.

### All-Out War Basis

Referring now to the extent to which our refineries must operate to support the war program, we must approach this ticklish topic on an all-out war basis with the full realization that neither the general public nor its government is apt to shed more than a passing tear at the failure of any non-essential enterprise, whether it be a race track or a refinery, to function due to economic dislocation. On the other hand it is just as vital that we have enough petroleum products as it is that we waste nothing (manpower, dollars, natural resources, or construction materials) by producing too much.

The thing greatly to be feared and hence to be avoided at all costs is the imposition from without the industry of a hard-boiled attitude which lacks realism because it does not appreciate the technological limitations which the refining industry must meet because of the character of its raw material. A perfect illustration of this attitude was recently called to my attention. Due to the drum shortage it was proposed to remove certain tretraethyl lead drums from domestic duty for service overseas without replacing them. When one of our experts protested that if the refineries failed to receive their tetraethyl lead they would be unable to market their gasoline and would have to shut down operations the first response was—"So what—we are fighting a war and civilians don't need gasoline." Those same refineries had to run to produce fuel oil vitally needed in the locality.

It appears to me that the industry still has much to do to educate the layman to the fact that you can't have any petroleum products without producing some gasoline and, at the same time, to convince everyone—the public-government generally—and the military in particular—that only the gasoline which is actually needed is going to be produced.

Fortunately we can approach the question of how hard our refineries must work without becoming involved in argumentation as to how much motor gasoline can or should be consumed in the present emergency. We can tackle it from another angle entirely, that is, how much crude must we run to produce the essential war products which we must have? Aviation gasoline, butadiene, and toluene are three essential products for which production has been definitely programmed. We all know that these products are essentially mere by-products of refining operations although enormous strides have been taken in the past few months to increase the yields obtained. In a large measure, these three vital products will be produced in the same refineries. A year hence, a certain number of barrels of crude oil per day (which I shall call "X" barrels) will have to be run to attain the programmed production, although it must be understood that a fair share of the butadiene and toluene will be produced by chewing up naphtha stocks which would otherwise go into motor gasoline and practically all of the aviation gasoline is in effect abstracted from what would otherwise be motor gasoline.

A non-overlapping use of special crudes to produce aviation lubricants requires the running of an additional "Y" barrels per day to the above figure.

Petroleum coke is just as essential to the war program as is toluene and there are certain minimum essential demands for fuel oil and asphalt. Computing fuel oil and asphalt requirements on the basis of present requirements corrected for the probable effect of limitation orders, restricting the use of these products to essential war purposes and considering the extent to which these essential requirements cannot be met out of the crude run primarily for aviation fuels and lubricants, toluene and butadiene and aviation lubricants, we have computed that it will still be necessary to run an additional "Z" barrels per day of crude to meet these requirements.

A totaling of "X," "Y" and "Z" gives an answer as to how much crude oil must be run in the last quarter of 1943 and the answer, thus computed, is in excess of 3,800,000 barrels per day. Much of this crude oil must be run in the refineries producing aviation gasoline, toluene, and butadiene and the balance must be run in refineries best adapted to

[*Continued on page 134*]

# Wartime Plant Design

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Chief, Equipment Procurement Division, OPC

IN ATTEMPTING to discuss the subject of Wartime Plant Design, it will be my purpose to inform you with regard to past activities and to outline plans for the future in so far as these matters relate to the erection of war plants in petroleum refineries.

First, I should like very much to express my appreciation of the prompt manner in which the refining industry has cooperated with the Office of Petroleum Coordinator for War in this connection. Irrespective of the many requests that we have made for material lists, progress reports and countless other data, to say nothing of the many similar demands made by the other agencies in Washington, the petroleum-refining industry as a whole has responded to our inquiries in a manner which has proved to be quite helpful.

The manner in which the industry has utilized substitutes, has developed short cuts, and has refrained from using excessive factors in their plant design, all for the purpose of saving critical material, has been appreciated not only by the War Production Board but also by our office. Most of the activity in this particular connection has been initiated by the industry itself.

Many of the refiners and the engineering companies have drawn up detailed specifications on the subject of wartime plant design, which have been issued in the form of a directive to their own engineers. These specifications have been made available to the industry as a whole. In many instances, they have gone to the extreme in their effort to save critical materials. The enumeration of some of the things that have been done in this respect should be a matter of general interest. Several companies have been able to work over old compressors so as to eliminate the necessity of purchasing new ones. This particular activity has contributed to a large degree toward making it possible to secure a sufficient number of compressors to complete the entire program. Brick and concrete stacks have been substituted for steel. In numerous instances old tankage has been cut down and reassembled, thus saving considerable steel plate even though the process represented a greater expenditure of money than would have been the case had new tanks been purchased. The specifications for valves and for tubing have been simplified in order to facilitate their production and also for the purpose of saving critical alloys. Transite and concrete are being used extensively instead of metal. Cast steel, nozzles, and flanges built up from plate have been substituted for forgings. These are but a few of the substitutions that have been made. Time will not permit the listing of them all.

### Short Cuts

The activities of the industry in curtailing the use of critical materials have not been confined merely to the use of substitutes. Many bottlenecks have been avoided and many short cuts have been developed by changes in plant design. These have been responsible for cutting down the number of valves, instruments, and heat exchangers, even though each item thus removed would have been considered necessary in normal times. The design of many vessels and towers has been changed so as to utilize a type of head that might possibly have been found in stock or was otherwise readily procurable. Overall excessive factors usually established as a means of fulfilling guarantees have been curtailed. In the opinion of our office, those engaged in the designing and erecting of refinery war plants have without exception conscientiously attempted to curtail the use of critical materials as far as possible.

The industry has manifested its spirit of cooperation in still another way. Reference is made to the redistribution of surplus materials and equipment. At the request of our office, practically everyone engaged in the petroleum refining industry has offered lists of used or surplus material to be redistributed among those engaged in erecting war plants. Though this particular activity has been in effect for only a comparatively short time, we now have a record of the transfer of such materials amounting to approximately a million dollars. The quantity of material thus handled is not as yet particularly imposing when compared with the overall program. However, it has been noticeable that the type of material thus transferred has in most instances supplied a dire need and has, as a result, made it possible for new war plants to go on stream, which otherwise would probably not have been the case for some time to come. In any event, this activity is to continue. There is, however, room for improvement in this connection. We have not always been informed when sales of surplus material have been made. Frequently those who have been interested in our lists have found that the material and equipment have already disappeared upon their institution of an inquiry. In undertaking this work, we had requested that each refiner should report each sale of surplus material by merely filing with us a copy of the invoice rendered at the time the shipment of the material occurred. These reports have not come in as requested. It would be exceedingly helpful to everyone concerned if they could always be made available promptly.

### Need Greater Effort

Even though we have had the hearty cooperation of the refining industry, we are sorry to report that we are not at all satisfied with the results which our office has been able to secure. It has frequently seemed to us to be somewhat ridiculous that more definite and positive results could not be secured. This remark is not made as a complaint or as an alibi; rather it is made for the reason that it indicates the necessity for greater effort—greater effort on the part of the industry and by the Office of Petroleum Coordinator for War.

There are still a number of items which are particularly difficult to secure. Reference is made to

* Before American Petroleum Institute, Division of Refining, Chicago, November 12, 1942.

instruments, heat exchangers, valves and forgings. Their scarcity is not only due to a lack of an even flow of critical materials but also involves manufacturing facilities which are called upon to produce enormous quantities over a relatively short period. Though, as stated above, the industry has done much to curtail the use of these items, it would seem the better part of wisdom for each erector to make further efforts along this line. In this connection, you may be interested in the activities of one of the major companies who recently instituted a program for curtailing the purchase of instruments. Their processing department made a complete survey of their instrument requirements in all plants being erected for the production of aviation gasoline. The instrument requirements were classified into three groups as follows:

1. Instruments considered absolutely essential for the operation of the plant.
2. Instruments that could be temporarily dispensed with by increasing the operating personnel.
3. Instruments that are necessary eventually for maximum efficiency, cost determinations, etc., but which could be dispensed with for a reasonable period without serious detriment.

As a result of this study, it was found that approximately 50 percent of their instrument requirements fell within Class 1, 15 percent in Class 2, and 35 percent in Class 3. In other words, it was apparent that their normal instrument requirements could be cut in half if their purchases were based upon sheer necessity. It is not the intention of this company to do away with their normal instrument requirements permanently. They are making provisions for the installation of the less essential instruments at a later date. If each war plant could be so handled over the next few months, not only would the completion of all projects be hastened but the procedure should undoubtedly be beneficial to the instrument manufacturer since his manufacturing activities would be extended over a longer period.

It is felt that a somewhat similar result could be secured in the case of valves. It would be difficult to say that the same thing could be accomplished in the case of heat exchangers. On the other hand, the statement has frequently been made that it would be impossible to justify many heat exchangers which are installed in modern plants if they were given the same economic consideration that controlled the project as a whole. It is conceivable, therefore, that in some instances heat exchangers could be eliminated as a temporary measure with provisions made for later installation.

In the matter of forgings, the situation continues to be acute. It is not thought that substitutes should be utilized except where absolutely necessary for the reason that substitutes as a usual thing require extra manpower. It is felt, however, that in those cases where forgings cannot be secured in time for plant completion, substitutions should continue to be used.

### Future Plans

The preceding comments treat largely of the activities of the industry and little has been said as to the future plans of the Office of Petroleum Coordinator for War. This is perhaps as it should be. No matter how effective the Office of Petroleum Coordinator for War may be in assisting this program, the real work has to be done by the industry itself. Nevertheless, the future plans of our office in this connection should be of some interest. For some time past we have endeavored to secure the approval of a plan by which each project could be scheduled for a definite completion date on the basis of freezing the materials necessary and distributing them by allocation. At first it was the thought that the rubber program, the aviation gasoline program, and the program controlling the erection of chemical plants needed in this connection could be correlated and the distribution of the materials handled as indicated. However, considerable opposition to the plan has developed because it is the intention of the War Production Board to eventually put the distribution of all materials for all purposes under allocation, and it was felt that the programs referred to above should not be so handled until the plan could be extended to embrace total requirements. The final decision as to the treatment of the above programs has not yet been made and though complete allocation will eventually come, it is apparent that the plan will not be available in sufficient time to take care of immediate requirements. In the meantime, however, we have been given considerable assistance by the War Production Board through their Determination No. 149. It reads as follows:

"All items in or for the continental limits of the United States of America originally rated AA-2 and now AA-1, pursuant to paragraph *e* under AA-2, of the military Priorities Directive dated June 12, 1942, in their entirety, are to be rated down to AA-3.

"Tools and equipment necessary in connection with the aluminum expansion program are to be rated up to AA-1 at once.

"The aluminum, alloy steel and high-octane gasoline expansion projects are to be rated AA-2-x.

"AA-1 and AAA may be given to whatever items in the aluminum, alloy steel and high-octane gasoline expansion projects as may be necessary; also where necessary in your opinion, schedules may be frozen to meet the objectives of these programs."

There are two points of particular interest in connection with this determination. First, not only has the rating of the 100-octane gasoline plants been raised but the rating of many plants being erected for military purposes within continental United States has been lowered. Second, and still more interesting, is the provision made in the last paragraph of the determination. This provides for additional assistance on such items as cannot be secured with a rating of AA-2-x. The additional assistance can be secured either through the issue of a triple A rating or a frozen order where such assistance is necessary. Broadly speaking, the present setup then permits us to utilize priority just so long as priority is effective. When it is no longer effective through the additional assistance provided for, we will be substantially allocating in cases of necessity.

As a result of this determination we are requesting the principals for whom each project is being erected to submit to our office a complete list of such items as cannot be secured under a rating of AA-2-x. In making a request for a rating higher than AA-2-x, it is necessary that the following information be given in complete detail: the name of the company holding the priority, the location of the plant, the end product which the plant will manufacture, and the Builder's Serial number which was assigned to the project when the priority was originally granted. The materials and/or equipment which cannot be secured with the AA-2-x rating should be tabulated

in vertical columns under the following headings: Name of Vendor, Purchaser, Purchase Order Number, Order Date, Description of Material, Quantity, Dollar Value, Promised Shipping Date, and Required Shipping Date.

It should be borne in mind that the Triple A rating will be granted only in case of dire necessity. Each item will be scrutinized by the War Production Board and by our office. The applicant should, therefore, use extreme care in determining the items requiring a higher rating so as to make sure that the higher rating is indispensable. It is felt that the War Production Board has gone a long way toward assisting our program by instituting the above procedure. Theirs is not only the job of getting our program completed but is one of fulfilling all requirements needed to win the war. We do not wish to destroy their confidence in our office or in the industry by applying for a higher rating than is absolutely necessary. Furthermore, if the procedure is abused, it will cease to function. We again ask, therefore, for the careful and prompt cooperation of the industry in this particular connection.

As intimated above, the War Production Board is at the present moment working on a plan by which the delivery of all materials needed for all things shall be scheduled and distributed according to their importance to the prosecution of the war. This plan is known as the Controlled Materials Plan. It will take time to make it effective. It will require a tremendous amount of effort on the part of industry as a whole and by the various governmental agencies. However, in the opinion of this office the plan has great promise. If properly executed, it should do many things. First, it will provide our office with a bank account of equipment and materials which will be frozen for our purpose and which we will be permitted to distribute according to a predetermined schedule. Second, it will permit those in authority to make decisions which may be depended upon since the materials allotted will be based upon a definite requirement of end product which has been predetermined and authorized. Third, it should permit the refiners, the engineering companies, the manufacturers, and the erectors, to lay their plans according to the availability of the materials needed with a reasonable degree of certainty that assigned completion dates can be met.

# Looking Ahead in Refining

[*Continued from page 131*]

serve the localities requiring the other petroleum products.

This figure of more than 3,800,00 barrels is a far different figure than has been reached at various times by various authorities but it at least has the merit of an objective treatment based on cold-blooded requirements figures and factual data on the yields anticipated of the war products required. It will be noted that in making the computation we have treated the war products as main products rather than by-products and we have assumed that industry and the general public will get along on the motor gasoline, lubricants and other civilian and industrial products which we have treated as by-products.

Certain factors, such as a demand for a further increase in aviation gasoline production may increase the load on our refineries but as far as possible increased production of aviation gasoline should be accomplished by operating on the crude oil which must run anyway to produce coke, asphalt, and fuel oil. Further, some refiners are already using motor gasoline fractions as a charging stock for catalytic cracking units producing aviation gasoline, and a continuation of this trend may be very helpful in disposing of excess naphthas.

Military demands are difficult to figure, at best, and an increased demand for off-shore shipments is well within the range of possibility. It might be possible to divert part of our motor-gasoline-by-product to such use but if more fuel oil is required an increased crude run may be inevitable.

Before concluding my talk I should like to refer briefly to a method of classifying refineries, which has sprung up in the past few months—namely, a division into so-called: "war products refineries" and "non-war products refineries." "War products refineries" have been stated to be those which produce aviation gasoline and its components, aviation lubricants, toluene, and butadiene. While this classification is useful, in fact necessary, it is probably a transitory classification. Just now when there is such an acute shortage of these products and it is necessary to force out every drop from whatsoever source, it has been necessary to classify any refinery producing, for example, codimer as a "war products plant" even though it produces less than 100 barrels per day of codimer—equivalent, perhaps, to 350 barrels of 100-octane gasoline—out of many thousands of barrels of crude per day. I believe such a classification has been proper and necessary but at the same time—in the long run any refinery which contributes its proper share to a balanced budget of the various petroleum products essential to win this war is a "war-products refinery."

Fuel oil, and for that matter motor gasoline insofar as it contributes to essential requirements, is just as much of a war product as toluene.

However, there is another method of classifying essential refineries which deserves our attention. It appears inevitable that those refineries which produce aviation gasoline, butylenes for butadiene or butyl rubber, and butadiene itself will have to crack heavier and deeper than even before to produce maximum yields of these war products. The motor gasoline by-product from such refineries will be relatively high in octane number and will probably require larger amounts of inhibitors to stabilize it against oxidation. On the contrary, refineries which do not produce these particular war products but which specialize in fuel oil or lubricants will have to reduce motor gasoline yields as much as possible and the motor gasoline output of these refineries—being straight-run gasoline—may be too low in octane number to compete with the highly cracked product and may require a wasteful use of tetraethyl lead for octane improvement. It appears that exchanges between refiners falling in opposite categories would produce a satisfactory motor gasoline without wastage of tetraethyl lead, with some saving in inhibitors, and that such exchanges should be arranged wherever possible to assist in solving the fuel oil supply program.

# We've left the wishful thinking up to Hitler

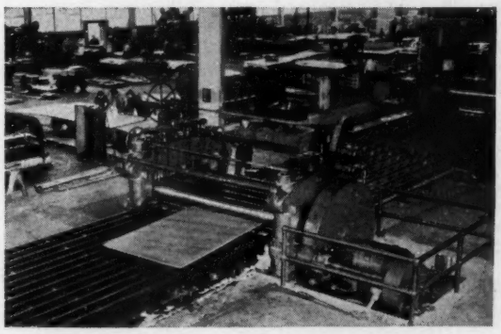
OUR enemies imagined we were soft, that we wouldn't pitch in wholeheartedly, that "business as usual" would hamstring our conduct of the war. The Axis must have felt confident for a while!

But already our warships are sliding down the ways a year ahead of schedule, our tanks and planes are helping to decide battles on every front. And the American oil industry is producing the oceans of specialized fuels, lubricants, explosives, to keep this great military machine in action. Behind such production achievements are the men, metals and machines in plants like this new plate mill of Revere's.

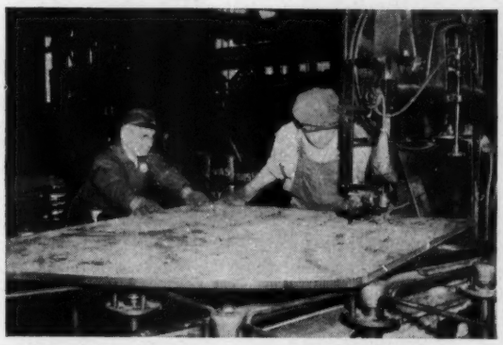
Laid out for maximum production of brass and other copper-alloy plates for condensers and heat transfer equipment, this new mill produces plates of the highest mechanical perfection. It is manned by Revere's skilled workers who have the "know how" of brass. It is turning out the kind of sound metal that can help swing the balance of military might to the side of the United Nations.

Revere tubes and plates meet all requirements of the oil industry for heat transfer equipment, including those arising from the use of the newest techniques. The Revere Technical Advisory staff is always ready to help with your problems. Write us.

Passing back and forth through the rolls, a red hot slab of copper base alloy is reduced to gauge thickness.



In a straight line, the alloy plate moves ahead to the flattening rolls from which it emerges as a smooth plate.



After rolling, the plate is cut and machined to the correct shape and size for the condenser in which it will be used.

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# Synthetic Chemicals from Natural Gas

DR. GUSTAV EGLOFF, Universal Oil Products Company
Before the Institute of Chemists

FOR MANY YEARS natural gas has been used mainly for heating and generation of steam and electrical power. In the last few years, however, the tempo of research and development has increased enormously. A much higher field of utilization for natural gas than as fuel is seen in the conversion of the hydrocarbons into superior aviation gasolines, lubricants, synthetic rubber, explosives, acetylene, anesthetics, plant life promoters, plastics, solvents, and many other chemical derivatives. A vast supply of these derivatives is available in natural gas produced in this country.

The processes and methods for such conversion in some instances are already in commercial use in the petroleum-refining and other industries. Other methods have been worked out in the research laboratories and the processes and yields that can be achieved are known; but it remains necessary for further research to establish the means to reduce costs to the level of commercial practicability. Another wide avenue for future development in the natural-gasoline and refining industries is thus foreseen.

Natural gas is consumed at the rate of over 2.6 trillion cubic feet per year. The United States has proven reserves of 85 trillion cubic feet and another 85 trillion as potential reserves. The yearly consumption of natural gas is equivalent in fuel value to 100,000,000 tons of coal or over 500,000,00 barrels of fuel oil.

In the Axis countries, methane gas is a widely used substitute motor fuel. As a matter of fact, there are over 107,000 compressed gas (methane, ethane, propane, butanes) propelled motor vehicles operating in continental Europe, which conserved about 2,300,000 barrels of gasoline for military use. The compressed gas is sold at filling stations in exactly the same way as gasoline in the United States. The gases are compressed under pressures up to 500° p.s.i. into steel cylinders attached to the running board of the car or under the floor of trucks and busses. Italy has a number of natural gas wells and is operating many busses and trucks plus a number of locomotives on methane gas. This looks like a desperate measure since it requires on the average about 135 pounds of steel for each of these high-pressure steel-alloy cylinders in order to withstand the high pressures. The products of fermentation of sewage are also used as a source of methane gas in Germany. Methane from coal gas is used for running motor vehicles of one sort or another in many of the European cities. Many coal hydrogenation units produce gasoline in addition to methane, ethane, propane, and butanes by the Bergius and Fischer-Tropsch process. The latter process will be referred to later in more detail because it is a potential source of many products. Busses, trucks, tractors, and power shovels, totaling over 25,000 in the United States, use compressed propane and butane. One truck company has liquefied butane functioning in a dual role as a refrigerant for fruits and meats and as motor fuel for the truck after the cooling has taken place.

### Variety of Uses

Hydrocarbons present in natural gas are methane, ethane, propane, butanes, pentanes, hexanes, and heptanes, etc. The first four of those are gases while from pentane on they are liquids useful as gasoline.

The individual hydrocarbons have a variety of uses in a number of industries. Propane has been suggested for use as a fuel for breaking in aviation engines on the "testing block," since it has a high octane value and is readily available. Such a procedure would conserve the 100-octane liquid fuels needed for fighter, bomber, and cargo airplanes in the war effort. Other uses for propane which have gained wide commercial application are as refrigerants and solvents in the refining of lubricating oils. Paraffin wax, asphaltic substances, naphthenic hydrocarbons and other materials are eliminated from lubricants when propane is used as the solvent. Over 50 percent of the world's lubricating oils are improved in quality by the use of propane.

Two hydrocarbons present in natural gas of great utility are isobutane and isopentane. Isobutane is the key hydrocarbon in the production of aviation gasoline by alkylation with olefins. In general, there is not enough isobutane available, hence it has been necessary to isomerize the normal butane present in natural gas to the iso compound. A number of commercial installations are in operation and under construction to isomerize normal butane to isobutane. Normal and isopentane are also present in natural gas, and it is highly desirable to fractionate out the iso compound due to its 91-octane rating in contrast to the normal which has an octane number of 64. Isopentane is blended with aviation gasoline in percentages ranging from 10 to 20, depending upon the other components in the final blend.

Olefinic hydrocarbons, not contained in natural gas as such, are important for many reactions not alone for aviation gasoline but for synthetic rubber and a host of other products. There are several routings to produce olefins from natural gas: one is high temperature, and the other by catalysis. The olefinic hydrocarbons which are now in great demand are ethylene, propylene, butylenes, pentylenes and butadiene. Natural gas, particularly the propane-butane fraction, when subjected to high-temperature cracking, produces ethylene, propylene, butylenes and butadiene. Normal butane is readily converted into butadiene in one or two stages by catalytic means at high temperature with yields reported of over 60 percent.

### Important to Aviation Fuel

A branched-chain paraffin, isooctane, is of great importance in the aviation fuel program. There are two methods whereby this hydrocarbon is derived, one is by polymerization in which isobutylene is polymerized to a dimer in the presence of phosphoric acid as a catalyst. Isooctene is the product, and upon the addition of hydrogen, isooctane results. Isooctane has an octane rating of 95-100. Another method of producing aviation gasoline is to polymerize the propylene, butylenes, and pentylenes present in cracked gases to a polymer gasoline under selective conditions which upon hydrogenation yields an aviation-gasoline-blending product of 90-octane rating.

The polymerization process has been largely replaced by the alkylation process in which isobutane is alkylated by butylenes in the presence of sulfuric or hydrofluoric acid catalysts. The resulting alkylate ranges in octane value from 91 to 96. The simplest of the olefins is ethylene which is used to alkylate isobutane at temperatures in the order of 990° F. and pressures up to 5000 pounds. This reaction produces neohexane having an octane rating of 94, an important hydrocarbon for aviation gasoline. In addition to alkylating ethylene and butylenes, propylene and pentylenes are also being alkylated with isobutane to form additional quantities of high-quality aviation gasoline. It is proposed in some type of operation to utilize the mixtures of propylene, butylenes and pentylenes in the alkylation reaction with isobutane using hydrofluoric acid as alkylating catalyst to produce alkylate of 91-octane rating highly suitable for aviation-gasoline blending stock.

An important aviation-blending fuel of an entirely different type is cumene, which is produced from the alkylation of propylene and benzene in the presence of solid phosphoric acid. A number of commercial units are now in operation.

Normal hexane and heptane are two

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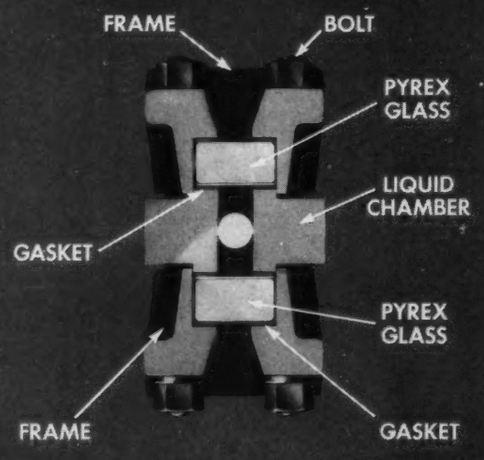


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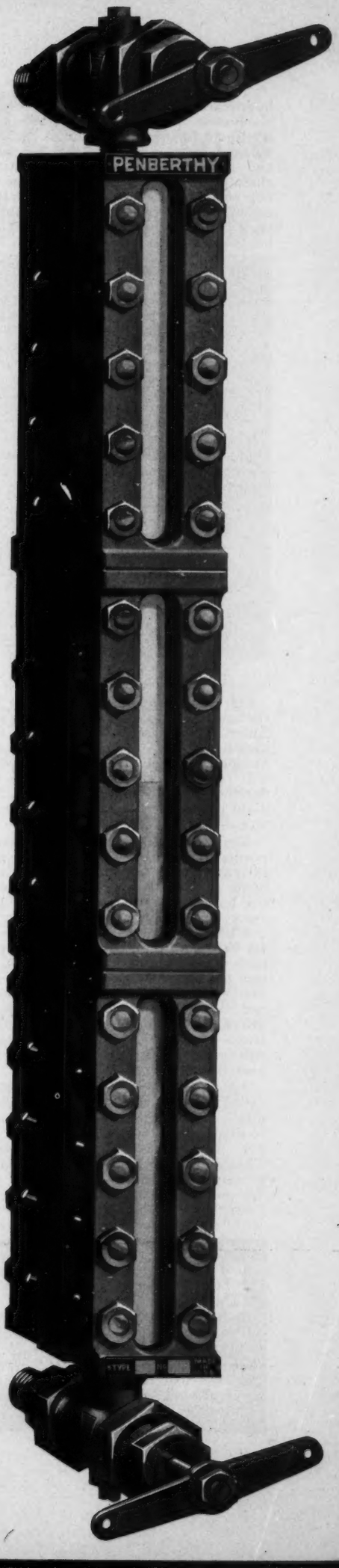


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hydrocarbons which from a motor-fuel standpoint are practically worthless unless their molecular structure is changed. Normal heptane has a 0 octane rating and hexane about 25. These straight-chain paraffin hydrocarbons, hexane and heptane, can be changed in configuration and also in their properties to improve their anti-knock properties. Hexane and heptane can also be converted into benzene and toluene—two important hydrocarbons for high explosives. Benzene is of vital importance in the production of styrene, which is produced by the alkylation of benzene with ethylene, forming ethyl benzene. Dehydrogenation of this compound yields styrene. When styrene (25 percent) and butadiene (75 percent) are mixed in the presence of a catalyst such as peroxide, polymerization takes place to form the synthetic rubber Buna S.

The synthetic rubber program in the United States calls for 886,000 tons as planned in September, 1942, distributed as follows:

| Types | Tons |
|---|---|
| Buna S | 705,000 |
| Butyl | 132,000 |
| Neoprene | 49,000 |

However, the recommendations of the Baruch Committee called for an increase of 220,000 tons to be apportioned as:

| Types | Tons |
|---|---|
| Buna S | 140,000 |
| Neoprene | 20,000 |
| Thiokol | 60,000 |

Out of the total 886,000 tons of synthetic rubber planned for the United States, 705,000 tons of it will come from butadiene and styrene. The normal butane that will be used for butadiene will represent about 80,000 tons a year derived largely from natural gas. One plant has a rated capacity of 66,000 tons and the other 15,000 tons a year.

More than 100,000 barrels a day of normal butane are available from natural gas. If this were used just for butadiene making, it would satisfy the entire butadiene requirements in our present synthetic-rubber program. Hence, it can be seen that the natural-gas industry has more than enough of the hydrocarbons which can be converted into raw materials to supply the entire synthetic-rubber program. Another important source of butadiene is through the dehydrogenation of butylene derived from catalytic cracking. This source will yield at the rate of 283,000 tons annually.

Another type of synthetic rubber is called Thiokol, made by chlorination of ethylene which is then refluxed with sodium polysulfide. The synthetic rubber program calls for 60,000 tons of Thiokol yearly. Hydrogen sulfide is present in varying percentages in natural gas and is readily converted into flowers of sulfur. This sulfur may react with caustic soda to produce sodium polysulfide. After reacting ethylene with chlorine, the dichlorethane is formed which reacts with the polysulfide, yielding Thiokol. The plans call for the use of Thiokol in retreading of tires.

Besides butadiene, styrene, and ethylene, a hydrocarbon of great importance is acetylene, used in the production of the synthetic rubber, neoprene; it is also the base material for nylon, a replacement product for silk. Calcium carbide is produced from coal and lime in electric furnaces requiring much electrical power. When water is added to this compound, acetylene is formed.

Natural gas or products therefrom under high-temperature conditions yield acetylene readily. Two commercial acetylene units are being installed at the present time, one of which will produce at the rate of 75 tons per day or 27,000 tons a year. Other units are also under way. The charging stock may be either propane, butane, natural gasoline or fractions from petroleum. It is believed that acetylene can be produced at a lower cost from processing natural gas than by the electrochemical method of producing calcium carbide. The natural gas industry has enormous volumes of propane and other hydrocarbons available to supply the whole needs of the United Nations for acetylene and its derivatives.

Germany uses acetylene made from calcium carbide converting it into butadiene by a four-stage chemical process. Neoprene rubber is made from acetylene treated with hydrochloric acid. This type of rubber will be produced at the rate of 49,000 tons a year in the United States.

The Russians start primarily with ethyl alcohol from grain to produce butadiene. Butadiene from ethyl alcohol derived from grain will be one of the sources in the United States synthetic-rubber program. The tonnage of butadiene from grain alcohol will be at the rate of 242,000 a year, representing about one third of the Buna S type production.

There are several other types of rubber which are in commercial production, one of which is the type based on isobutylene from dehydrogenation of isobutane from natural gas or from cracking of oil. Isobutylene is copolymerized with about 2 percent of butadiene or isoprene resulting in a product called Butyl rubber. In the government program this type of rubber will be produced at the rate of 132,000 tons a year. Butyl rubber, as of today, is not as good a synthetic rubber for tire use as the Buna S. Tires made of Butyl rubber have a mileage life of about 12,000 miles with a meximum road speed of 35 miles an hour. This will naturally be improved upon.

There is an important use for synthetic rubber which is fabricated so that billions of minute air cells are present; it is used as a liner in gasoline tanks in fighting, bombing, and pursuit planes. When a bullet goes through the tank, the rubber causes it to be self-sealing.

Another type of synthetic rubber is the acrylonitrilebutadiene which can be produced also from natural gas and is known as Buna N or Perbunan.

### Carbon Black

One of the necessary materials in the compounding of either natural or synthetic rubber is carbon black which is made from natural gas. Carbon black is an important component in tires or other rubber goods whether it is blended with natural or synthetic rubber, as the properties of rubber, particularly from the standpoint of the tensile strength and wearing qualities under service conditions, are greatly improved. During the year 1940 about 369 billion cubic feet of natural gas were converted, largely by the channel process (air oxidation), into carbon black with an average of 1.54 pounds per cubic foot of gas or about 285,000 tons, of which about 85 percent was used in tires. Furnace black appears to be superior for use in synthetic rubber.

The world's natural rubber production for 1941 was about 1,675,000 long tons of which the United States imported over 800,000 long tons. The United Nations have lost over 95 percent of the world's natural rubber sources and Russia has lost two of its synthetic rubber plants in the Ukraine.

With the tremendous increased demand for airplanes, tanks, motor trucks, ships, trains, gun mountings, etc., rubber is required in ever-increasing quantities by both the fighting forces and the necessary civilian users for the successful conclusion of World War II. A medium size tank requires 500 pounds of rubber, small pontoon bridges 1000 pounds, for flying fortresses the gasoline tank alone requires 500 pounds of bullet-sealing rubber, while a large bomber uses 1250 pounds, gas masks 0.75 pounds, and battleships between 75,000 and 150,000 pounds. Tires for large excavation trucks used by the army have a diameter of 9.5 feet and weigh over 3500 pounds. There are many hundred more products requiring rubber that are vital in the war effort, such as blimps, barrage balloons, rubber boats, rafts, and life vests and suits for flyers, hospital rubber needs, etc. Millions of soldiers on the fighting fronts require rubber in one form or another.

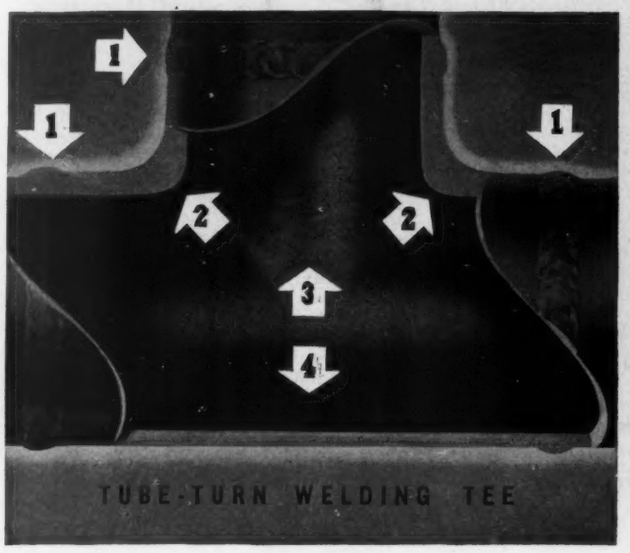
The synthetic rubber picture in the United States, with its 886,000 tons a year at plant costs of about $800,000,000 are already well under way. The Baruch Committee has recommended that this tonnage be increased to 1,106,000 tons a year. In addition to being the arsenal for many other war products, synthetic rubber will also have to come from the United States to supply our allies' needs. It may well be assumed that even 1,106,000 tons of synthetic rubber will be too low for the United Nations' requirements.

### Synthetic and Natural Rubbers

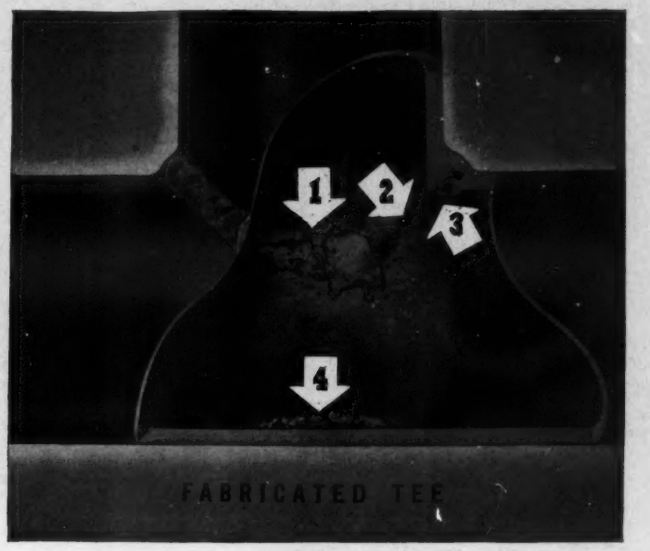
The question arises now: Is the synthetic rubber product equal to the natural? In general, one can say that synthetic rubber is at least equivalent to the natural; the chemist's goal is not necessarily to synthesize a duplicate of natural rubber, but it is certain that whatever properties rubber has that are needed will not only be duplicated, but radically improved and new ones added. Synthetic rubber is superior to natural rubber in gasoline, oil and chemical resistance. The synthetic product is more stable to light and air, and has greater wearing properties. Some trucks using synthetic-rubber tires have gone over 35,000 miles. Sidewall tire strength is greater, meaning greater safety and better road gripability. The latter property has been tested out thoroughly on wet and muddy roads. Tests on hills with different trucks have shown that the synthetic-rubber-tired vehicle goes up a hill with very little side-slipping, whereas the tires of natural rubber slipped all over the road. On curves when operating the car at high speeds, the synthetic tire is safer than the natural.

With the number of research men in the field of synthetic rubber, with expenditures of millions of dollars yearly, one can feel confident that synthetic rubber tires will evolve with a life of at least 100,000 miles or, expressed an-

# Why TUBE-TURN WELDING TEES provide strong, safe, easy-to-weld branch connections




(1) Easy circumferential butt welds cut installation time, make sounder, safer joints. (2) Easy sweeping curves reduce friction and pressure loss to a minimum. (3) Smooth inside walls assure even flow and add to the long life of the connection. (4) No accumulation of slag.



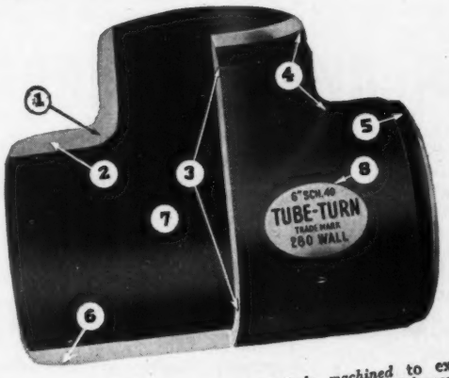

(1) Joining a branch into a main with an intersection weld makes a weaker, less sound connection. (2) Gaps and irregularities caused by uneven cutting must be filled by welder. (3) Sharp corners and jagged angles are poor piping practices. (4) Possible slag accumulation can impede flow and seriously injure valves.

**COMPARE the two cut-away illustrations above point by point for *proof* of the unmistakable superiority of welding tees.**

**It takes *fewer man-hours and far less trouble* to install a Tube-Turn welding tee into a piping system than to fabricate a branch connection, a vital factor in today's plant expansion and modernization for war needs. Other major advantages of these seamless welding tees are the *greater strength, longer life,* and *smooth flow* secured.**

**The design and construction of Tube-Turn welding tees *add to the strength of the entire piping system* by reinforcing these crucial points.**

## 8 REASONS FOR SPECIFYING TUBE-TURN WELDING TEES




1 *Extra thickness at crotch* reinforces where highest stress occurs.

2 *Reinforcement along top of run* adds needed strength here.

3 *Reinforcement on sides*—also a point of high stress gradually tapers toward end of outlet and bottom of run.

4 *Longer outlet* permits faster lining up and ample room for rod manipulation.

5 *Ends machined* to exact pipe wall thickness—easy to align and weld.

6 *Increased thickness at bottom* adds to full strength without excess weight.

7 *Smooth inside walls, curved inner crotch and special manufacturing process* assure even flow.

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other way, the tires may well outlive the motor car.

As far as the author is concerned, synthetic rubber in the United States is here to stay and will be a permanent industry during the next peace period. With the fall of Singapore our greatest source of natural rubber was cut off. Natural rubber (December, 1941) cost about 22 cents per pound. The price ranged through the years from 3.5 cents to over $1.00 per pound. It can be stated that synthetic rubber in mass production will cost less than 15 cents a pound.

Does this mean that natural rubber will not have its uses? As far as tires are concerned, it will not have the dominating position it has held heretofore. One may be certain that as good as synthetic rubber is today, it will be far surpassed by that yet to come. The properties of the rubber desired will be under close chemical control based upon the high purity of the components started with, catalyst, and precise conditions to yield the finished product. Natural rubbers vary widely in properties, due to many factors. Producers of natural rubber depend upon the life cycle of the rubber tree, climatic and soil conditions, while the chemically produced rubber will have the exact properties for which its structure and use was designed. Natural rubber contains a number of unknown components, whereas synthetic rubber has one, two or three components of known characteristics.

Natural gas is an important source of high explosives. Natural gas in some parts of the country is being cracked into hydrogen which is combined with the nitrogen from the air, producing synthetic ammonia. The ammonia is readily oxidized with air into nitric acid. Combination of the ammonia and nitric acid produces ammonium nitrate.

In World War I the maximum toluene production was at the rate of 15,000,000 gallons a year and practically all came from coal carbonization plants to derive coke for steel making, with toluene as a by-product. The toluene production in World War II from coal carbonization is at the rate of over 25,000,000 gallons a year. According to published reports the demand for toluene is from 250 to 300,000,000 gallons a year—the difference between the volume of toluene from coal and the total demand will come from petroleum, i.e., 10 to 12 times as much from petroleum. In comparing the two wars the increased demand for toluene is from 16 to 20 times. On a TNT basis World War I called for 150,000,000 pounds, whereas the present war calls for 3,000,000,000 pounds a year. Benzene is readily converted into carbolic acid or phenol through chlorination and hydrolysis. Combine the phenol with nitric acid and picric acid is the result, a high explosive, and when synthetic ammonia reacts with picric acid, ammonia picrate is formed, another high-grade explosive. The ammonium picrate is relatively stable, but when picric acid is used, it reacts readily with iron to form iron picrate, a very unstable compound that has a habit of exploding when least expected. That is what happened in a number of plants in World War I.

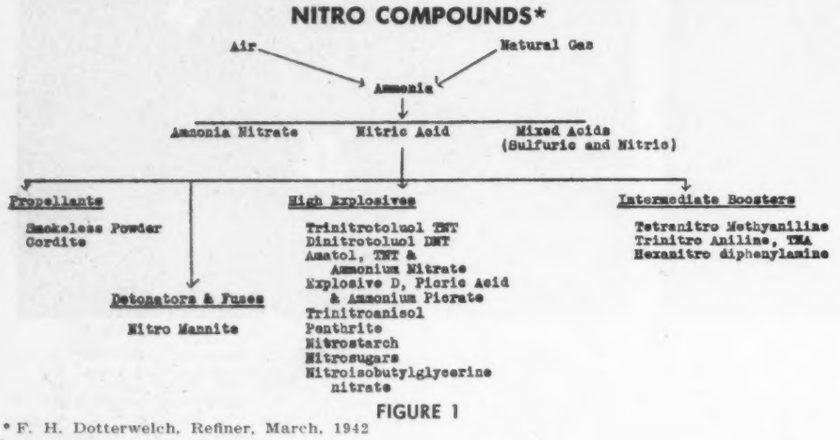


FIGURE 1

* F. H. Dotterwelch, Refiner, March, 1942

Many natural gases contain hydrogen sulfide which when oxidized with air is converted to sulfuric acid necessary in so many arts, particularly high explosizes. A number of commercial units are producing sulfuric acid based on hydrogen sulfide or elemental sulfur produced from natural gas as a starting material. So we have sulfuric and nitric acid, both produced from natural gases, raw materials necessary for high explosives needed in this present war, some of which are on a scale over 20 times that of World War I.

An important substance in war is glycerine for the production of trinitroglycerine, the commonest form of which is dynamite. The main source of glycerine has been in the splitting of fats to glycerine and fatty acids in the soap-making industry. As is well known, a campaign is on for the conservation of cooking fats of all kinds which has been requested by our government. These fats have many uses, one of them being the manufacture of soap and glycerine. A few years ago a glycerine-making process was developed by the petroleum industry starting with propane or propylene, which are chlorinated and then hydrolized to glycerine. The glycerine is then nitrated to trinitroglycerine.

Nitroparaffins from natural gas may well develop into one of the newer and valuable sources of high explosives. Methane gas when nitrated produces tetranitromethane. This compound is the most destructive explosive known to man. This product is a very high explosive, extremely difficult to handle. About 20 years ago in a university laboratory in Switzerland, they were working with tetranitromethane which is usually a reaction product of toluene nitration in small concentrations. Ten grams of tetranitromethane killed 10 individuals, wounded 20, and nearly wrecked the building. Unfortunately, no commercial process has been worked out to make this product available for use by our armed forces. Figure 1 shows the importance of nitro compounds in the manufacture of explosives.

### Anaesthetics

Anaesthetics are vital in a world at war. One of the primary needs of the medical profession has been anaesthetics which do not have post-operative dangers due to pneumonia and nausea. Ethylene has been shown to have properties superior to those of ether and nitrous oxide. Deep surgical anaesthesia is readily induced by ethylene and insensibility to pain comes rather quickly. A general feeling of well being and comfort with no harmful after effects is present when ethylene is used. Cyclopropane, although known since the year 1682, was still a laboratory curiosity until the end of 1930 when it was first applied in human anaethesia. It has been rather widely adopted since as being one of the safest anaethetics. Cyclopropane produced from either propane or propylene by a series of chemical reactions is less explosive in the hospital than either ether or ethylene.

Olefins have been investigated as fruit-ripening agents and for use in inducing an accelerated plant growth. The first gas to be utilized for this purpose was ethylene, which was first used in an impure form — the fumes from a kerosine stove were found to be effective in bringing about the ripening of citrus fruits. Ethylene was the agent responsible for the ripening.

Ethylene and propylene stimulate potato growth, and have been found to shorten the growth season for tomatoes, grapefruit and oranges. The German Botanical Society reports that up to a 100-percent increase in the yield of potatoes can be obtained when the seeds are treated with ethylene gas. "The tubers of plants grown from seed potatoes which had been exposed for 24 hours to atmospheres containing 7.5, 15 or 30 percent gas at 65° F. were more numerous, larger and richer in vitamin C. It is claimed that this process is cheaper than the application of hormones."

Researches by the Russians on butylene gas showed a stimulating effect on the maturing time of such trees as the walnut, peach, apple, cherry, plum, apricot, and pear. In periods when the season is too short to allow the full maturing, due to winter weather being so prolonged that flower formation and fruit setting are delayed, butylene may be used to hasten the growth period. The procedure adapted to plant treatment consists of enclosing the trees in tents or gas-tight covers for about two weeks before the normal or desired leafing, i.e., start of the growth cycle. Butylene is passed into the tent in about one part per 100,000 parts of air, at temperatures between 69° and 100° F., for a period of 1 to 2 hours.

Another method for ripening fruits is to use pentylenes, hexylenes, and heptylenes from cracked gasoline. Addition products of the unsaturated hydrocarbons derived from cracking, such as ethylene di-iodide, ethylene butyrohy-

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drin, ethylene acetohydrin and ethylene formohydrin are also used as agents for furthering the ripening of fruit.

The skin of the green fruit absorbs the olefin or olefin derivative, destroying the chlorophyll. The advantage in using liquids as ripening agents is that they are absorbed and continue their action after removing the fruit from the liquid; after storage under normal conditions, the ripening is complete.

Natural-gas hydrocarbons can be used as basic materials for the synthesis of plastics after forming olefinic hydrocarbons. There are three basic reactions which in various combinations are used to produce plastics from the derived hydrocarbons; they are oxidation, halogenation (mostly chlorine is used) and polymerization. Stemming from these reactions, the entire plastics industry has built up new materials and replacement products for many structural materials and rubber. Figure 2 shows some of the derivatives of the unsaturated hydrocarbons from natural gas.

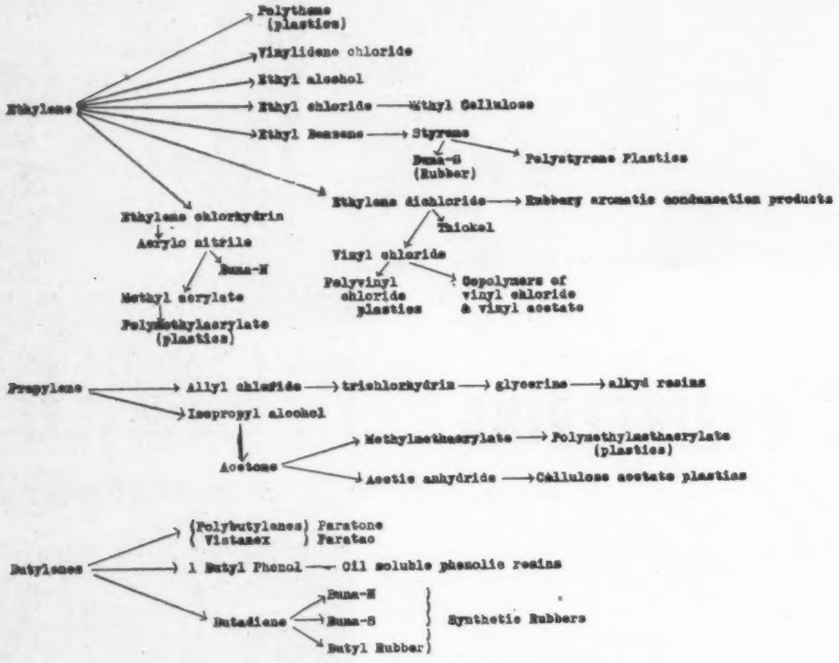


FIGURE 2

The materials which are outlined in the chart have many uses besides plastics as the intermediates shown are a typical cross section of the chemicals derived from natural gas. The finished plastics, as well as the intermediate compounds, find use as paints, varnishes, addition products for lubricating oils, and molded materials. Their intermediates are used as solvents, cleaning agents, and as additives for various types of products.

The coming importance of plastics cannot be over-emphasized at this time, since airplane manufacturing is calling for more of the plastics for use in plywood planes. Steel now used in many places is being replaced by plastics. In the war industries where the fabrication of planes takes place, the methylmethacrylate resins are used as the transparent non-shatterable parts where great visibility is necessary, and this will undoubtedly be used by the automobile industry after the war is over. A high degree of visibility from all over the motor car will be worked into the new design requiring less supporting frame work, and a clear vision rooftop with sliding window will undoubtedly take the place of present designs. In fact, the motor car of the future may well be substantially all plastics.

At the present time any of the components necessary for the manufacture of plastics of all types can be made from natural gas. One of the important substances for the Bakelite type of plastic manufacture is formaldehyde, made largely from the methanol or wood alcohol by the catalytic reaction of carbon monoxide and hydrogen at high pressures. For a number of years formaldehyde and methanol have been produced from the oxidation by air of natural gas. This process can be readily expanded to produce all the formaldehyde necessary in the ever expanding Bakelite program. The phenol or carbolic acid and cresols, etc., are also potentially available from natural gasoline.

One big field of research and development that merits discussion is carbon monoxide and hydrogen or the water gas reaction to form hydrocarbons. In the United States we have over 2.6 trillion cubic feet of natural gas yearly production. This gas contains about 90 percent of methane which can be converted into carbon monoxide and hydrogen by high temperatures in the presence of steam. In Germany the Fischer-Tropsch process has been developed to produce oil from carbon monoxide and hydrogen at the rate of about 15,000,000 barrels a year. The hydrocarbons produced are methane, ethane, ethylene, propane, propylene, butanes, butylenes, gasoline, gas oil, and diesel oil to solid paraffin wax. The reaction takes places in the presence of a catalyst, which may be oxides of nickel, chromium or cobalt, using temperatures of 400° F. and pressures of the order of 200 pounds.

The gasoline produced by the water-gas reaction is poor in quality with about a 40-octane rating. The gasoline has to be cracked thermally or catalytically into higher-octane fuel. The gasoline fraction boiling up to 300° F. contains olefins which polymerize with each other to form lubricating oil. These lubricating oils are produced commercially in Germany and some of them are high grade. The balance of the gasoline fraction, the paraffins, hexanes, heptanes, octanes may be thermally cracked under controlled conditions to make more olefins which in turn are converted into lubricating oil by polymerization. A portion of the synthetic oil is a high-grade diesel oil with octane number of over 100. The diesel-oil fraction is blended with lower-grade diesel oils to improve its quality.

Paraffin wax, which is also derived from the water gas reaction, is oxidized with air to make fatty acids. The fatty acids are reacted with potassium or sodium hydroxide, and soap is produced. The last report out of Germany is that one small cake of soap is allotted per inhabitant per month, and much of it comes from this paraffin wax. In 1938 and previous years also, conversion of paraffin wax from the water-gas reaction, coal carbonization, and petroleum, was carried out, forming fatty acids. In addition, these fatty acids are combined with synthetic glycerine to make fats for food. Glycerine and soap are produced (United States) from the splitting of fats, but the Germans are reversing the process in order to produce edible fats for food. It is not the type of fats to which we are accustomed, but it is helpful under the critical food conditions existing in Europe.

An enormous amount of research is going forward in a study of natural gas and gasoline to enhance their importance in the war effort—through solvents, plastics, high explosives, acetylene, synthetic rubber, lubricating oils, and aviation gasoline. As a matter of fact, if one starts with methane gas alone, all of the known synthetic products that man has produced in organic chemistry can be derived, and there are over 500,000 different ones. Any synthetic product desired can be produced at a price; the hydrocarbons are all potentially available to be converted into the manifold products that man requires in a modern world.

## Too Much Rubber for One Battleship

Led by a letter from Walter Swaney of Kerotest Manufacturing Company, many subscribers have expressed doubt of the accuracy of an underline for an illustration, page 120, in October PETROLEUM REFINER, crediting one battleship with requiring 75,000 tons of rubber. Since that amount of rubber runs higher than the total weight of any battle wagon afloat or building, the error is obvious.

The correct figure is 75 tons.

Another error in the October issue occurred in the spelling of the name of O. T. Aepli, who with Heinz Heinemann prepared digests of United States patents on synthetic rubber, page 355. The two are with Attapulgus Clay Company, Philadelphia.

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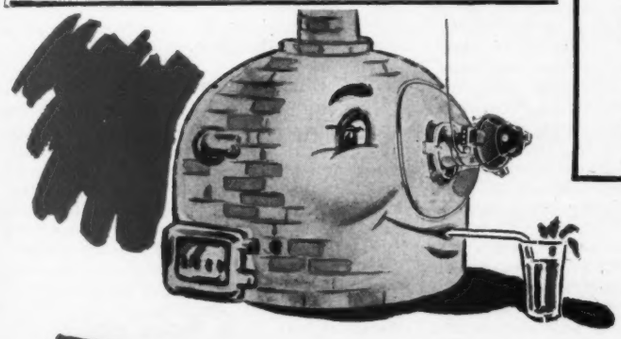

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# Chemistry of Synthetic Rubber

## Supplement to the Report of the Baruch Committee On Synthetic Rubber

STRICTLY speaking, no material has yet been produced which warrants the name of synthetic rubber—at least in the sense in which we speak of many other synthetic substances. Synthetic indigo, for example, is identical in every way with the dye-stuff prepared from the indigo plant. Likewise synthetic camphor may be manufactured which is identical in every way with the substance obtained from the camphor tree. On the other hand no one of the synthetic rubbers so far developed—and at least a thousand more or less rubber-like substances have been produced—is exactly the same as natural rubber either in its chemical make-up or its physical properties.

The molecules in natural rubber are of very great size and are constructed by the multiplication of a basic unit composed of five carbon atoms. This unit is known as isoprene. Rubber-like materials have been prepared synthetically by starting with artificially manufactured isoprene and causing the units to combine together to form a large molecule.

Although such material is identical with natural rubber in chemical composition it still differs appreciably in physical properties because the artificial conditions under which the isoprene units combine do not produce the same-size molecule with exactly the same architecture as that found in nature. If isoprene could be manufactured readily it might well be the best raw material for the manufacture of a synthetic rubber. Lacking any process for the production of isoprene economically on a large-scale basis, chemists have turned in their studies to closely-related simple chemical compounds.

One of these is butadiene which differs from isoprene in having four carbon atoms in its structure instead of five. Another is chloroprene which differs by having four carbon atoms and a chlorine atom.

The molecules of butadiene may be caused to combine together by the action of metallic sodium to form a rubber-like material often known as Divinyl rubber. This is the synthetic rubber which has been produced in Russia for a number of years. On the other hand, the molecules of chloroprene will combine to form a giant molecule with rubber-like properties known as Neoprene. This product has been commercially in production in this country for a number of years. All of these processes by which small molecules join up to form a large one are known as polymerization.

It has been found in recent years that highly satisfactory rubber-like materials may be formed by allowing mixtures of butadiene and relatively small amounts of other compounds to polymerize. In this chemical reaction, large molecules are formed in which both the butadiene unit and the other molecule are built into a large and complex aggregate. When two or more different kinds of molecules are involved in the polymerization the process is known as co-polymerization. The material which results when styrene and butadiene are co-polymerized carries the name of Buna S. This is the synthetic rubber which will be produced in largest quantities under the present government program.

Another co-polymer which has recently received considerable attention is that known as Butyl rubber. This material results from the co-polymerization of isobutylene and small quantities of butadiene or isoprene. Flexon is the name given to a Butyl rubber which is prepared in a special way requiring little apparatus but the maintenance of low temperature by the use of solid carbon-dioxide (dry ice).

### Butadiene and Its Cousins

To complete the picture as it applies to the projected program for the supplying of synthetic rubbers in this country, there should be considered briefly the manufacture of butadiene, chloroprene, and isobutylene, which are the basic constituents in the processing of Buna S, Neoprene, and Butyl rubber.

Butadiene is a close relative of a compound known as butane which occurs in large quantities in natural gas. Butadiene differs from butane only by reason of its relatively smaller contents of hydrogen. Even closer in its relationship to butadiene than butane, however, is the gas called butylene which is a by-product of the petroleum-cracking

**Comparison of Synthetic Rubbers and Reclaimed Rubber with Crude Rubber as a Tire and Recap Material***

| | Manufacturing Efficiency | Tread Wear | Carcass Failures | Suitability as a Recap | For Inner Tubes |
|---|---|---|---|---|---|
| BUNA S (new tires and recaps). | **Good**—<br>Mixing 40-70%<br>Building 80-100%<br>Curing 100% | **Good**—Tests shown about 90% mileage of crude rubber. | **None**—If 10% crude rubber is used. | **Good**—Tests show about 90% mileage of crude rubber. Curing time about the same as crude rubber. | Apparently satisfactory. |
| NEOPRENE (new tires and recaps). | **Good**—<br>Mixing 40-65%<br>Building 75-100%<br>Curing 50% | **Good**—90% mileage of crude rubber at normal speeds; 125% under severe service. | **None**—No carcass failures reported in tires tested recently. Some failures in earlier tests. | **Good**—Tests show 90-110% mileage of crude rubber recaps. Curing time longer. | Apparently satisfactory. |
| BUTYL (new tires). | **Good**—<br>Mixing 100%<br>Building 100%<br>Curing 70-75% | **Fair**—40-50% of mileage of crude rubber. | **Frequent**—65% of first tires failed, largely due to blisters which developed in the manufacturing process. | **Promising**—Adhesion with crude rubber was poor at first, but a recent development appears to have overcome this difficulty. | May be developed, but not yet satisfactory. |
| FLEXON (new tires). | **Fair**—Similar to experience with Butyl. Manufacture slow; material soft and sticky. | **Poor**—Mileage in tests not more than 40% that of crude rubber. | **Frequent**—Tread and ply separation common in the few tires tested. Later tests show improvement, as with Butyl. | **Promising**—Same difficulties as with Butyl. | Unsatisfactory. |
| THIOKOL (recaps). | | **Poor**—Thin, smooth recap gave only 14% of mileage of crude rubber; 28% for comparable thickness. Regular non-skid tread gave 20% | | **Good**—Curing and cooling time somewhat longer than for crude or reclaimed rubber recaps. | Unsatisfactory. |
| RECLAIM (new tires and recaps). | **Good**—Equal efficiency in milling, etc.; cures somewhat faster than natural rubber. | **Poor**—About 20-25% mileage of crude rubber. | **Infrequent** | **Good**—Curing time same as for crude rubber. | Fairly satisfactory. |

* Comparisons are based on average experience in latest tests, operating at speeds around 40 miles per hour. The mileage life of a crude rubber tire at this speed is considered to be about 35,000 miles.

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process for the manufacture of gasoline.

All these three substances—butane, butylene, and butadiene—have four carbon atoms per molecule; they differ only in their degree of dehydrogenation—that is, in their content of hydrogen atoms. Butane has 10 hydrogen atoms, butylene has 8, and butadiene 6.

It sounds as though it should be an easy matter to ring the changes between these various gases by the removal of hydrogen atoms. In practice it is by no means simple. In general it takes high temperatures and special substances known as catalysts to dehydrogenate molecules, and butane and butylene are no exception. However, it can be done and the process of manufacturing butadiene from the other two petroleum compounds depends on either the removal of four hydrogen atoms from butane or of two hydrogen atoms from butylene.

It is unfortunte from the point of view of endeavoring to give a simple explanation of the chemistry of rubber synthetics that the situation is still further complicated by the intrusion of the material called isobutylene in the rubber picture. Isobutylene contains the same numbers of carbon and hydrogen atoms as does butylene, and differs from butylene only in the architecture of the molecule—the arrangement of the atoms. Because of this difference it is only distantly related to butadiene and cannot be converted into butadiene. As has been pointed out, however, it has the ability of being co-polymerized with small quantities of isoprene or butadiene to form Butyl rubber.

Both isobutylene and its cousin, butylene, share one characteristic in common, namely, that both are valuable materials for the manufacture of high quality aviation fuel—in other words, high octane gasoline. The importance of this fact to the war program rests in the interconnection of the preparation of butadiene from petroleum and the manufacture of aviation fuel and other petroleum products.

Finally, the fact must be recorded that relatively small quantities of butadiene and still smaller amounts of isoprene are formed when gasoline or higher boiling mixtures of hydrocarbons are subjected to the cracking process; i.e., heated to a high temperature. This "thermal process" of manufacturing butadiene has been in operation in this country on a considerable scale for several years.

However, in previous high-thermal cracking, butadiene has appeared as a by-product. Hence this source is not available for the manufacture of the great quantities of butadiene needed for the present synthetic rubber program. The sizes of plants required for manufacture of butadiene by this method would be excessive and the disposal of the main products of the process a major problem; furthermore, because of the high temperatures employed (1300° F.), the life of some of the crucial equipment is short.

This is the reason why the chief reliance in the government rubber program, insofar as petroleum is concerned, has had to be in processes starting from butane or butylene.

### Alcohol Process

In addition to petroleum products, alcohol may also be used for the preparation of butadiene. This can be accomplished in several different ways, which amount to the union of two two-carbon units of alcohol into the four-carbon butadiene unit by the processes of dehydration and dehydrogenation—that is, by the loss of water and the loss of hydrogen.

The Germans employ four steps in this process. The American process, by which one quarter of the butadiene under the government rubber program will be manufactured, accomplishes the same transformation in two steps. The Russian and Polish processes accomplish the entire transformation in a single step by the use of a special catalyst.

It should be remarked here that in the public discussion of the various processes of manufacturing butadiene from either alcohol or petroleum there has been a tendency to lay altogether too much stress on whether a process involved one step or two steps. Actually in all the processes there are many separate phases from the point of view of the chemical engineer and only a detailed analysis of the very complicated blueprints of the plant layout enable one to pass judgment on the comparative simplicity and merits of the operation. In one of the plants for the manufacture of butadiene under the government program, for instance, over 600 separate engineering drawings are required.

Alcohol can be prepared by the fermentation of carbohydrates material, such as grain or molasses, or from the carbohydrates found in sawdust or sulfite liquors from good pulp manufacture. It also can be manufactured from ethylene which, in turn, is a by-product of petroleum, or from acetylene which is manufactured from limestone and coke.

These many routes, starting from widely unrelated materials and all passing through the alcohol process for the production of butadiene and eventually of Buna S rubber, have led to the appearance in print of many erroneous chemical interpretations and conclusions. For instance, we may speak of Buna S as being manufactured "essentially" from wood-pulp or grain or petroleum or limestone and coke, and yet in each case we might be endeavoring in simplified language to describe the preparation of butadiene through a single route—the alcohol route—and its subsequent conversion to Buna S or Divinyl rubber.

Still another process for making butadiene from grain has recently been developed and is being experimented with by the Department of Agriculture in its laboratories at Peoria. This involves a special fermentation of the grain to produce butylene glycol, which, in turn, through a series of chemical reactions, is turned into butadiene and then into Buna S rubber.

### Neoprene

We have mentioned that the Germans, as far as is known, start their process from limestone and coke. At this point we may conclude our account of the chemistry of these substances by a description of the American product Neoprene, which also traces its ultimate origin to the same substances.

In a high-temperature electric furnace, limestone and coke yield calcium carbide which when treated with water gives acetylene. The Germans transform acetylene to butadiene by a four-step process which is essentially one of the alcohol routes for the manufacture of this gas. In this country two molecules of acetylene are combined and a molecule of hydrochloric acid (which comes from salt) then added. The product is chloroprene—the four-carbon compound which differs from isoprene the unit of natural rubber, by reason of the presence of one chlorine atom. Chloroprene is polymerized to Neoprene.

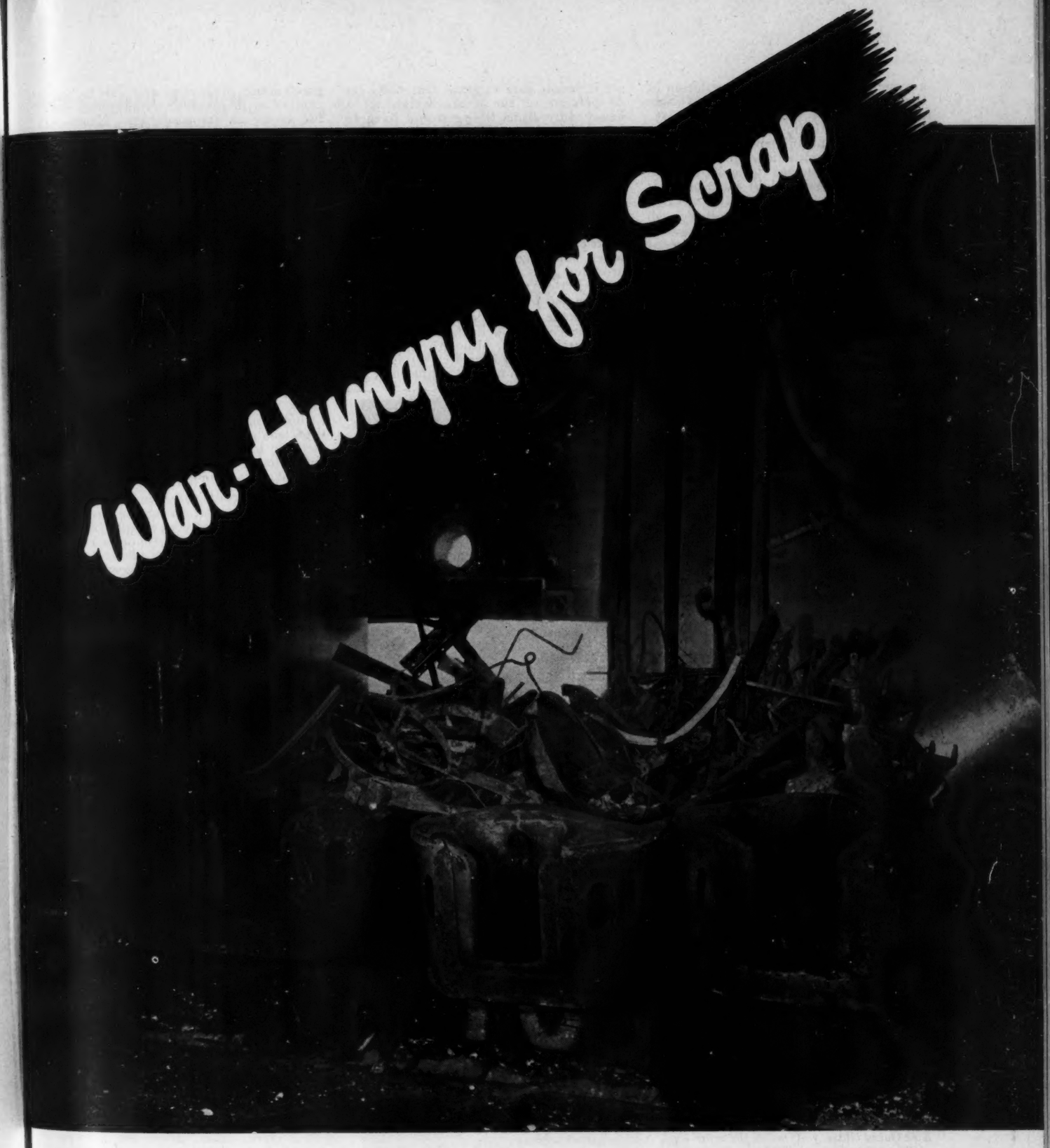
One final basic fact regarding synthetic rubbers must be mentioned. To manufacture tires from either natural or synthetic rubber, the material of the tire must be (a) milled and (b) compounded; then the tire must be (c) built and (d) vulcanized or cured. All four processes depend on the nature of the rubber-like substance or substances used in fabrication. Buna S and Neoprene resemble natural rubber more closely in structure than Butyl rubber. Hence they can be milled and cured more nearly in the same way as natural rubber.

Buna S, Neoprene, and Divinyl may properly be regarded as members of the same family as natural rubber. Other synthetic rubber materials now in the public eye are more distantly related. Chief among these now much discussed is Thiokol. It is manufactured from ethylene chloride (a product of ethylene and chlorine), sulfur, and caustic soda. The architecture of the Thiokol molecule bears little resemblance to that of natural rubber—in its structure a sulfur atom plays a predominant part.

Other rubber-like materials have been manufactured by the preparation of large molecules by various chemical reactions from a wide variety of natural products. The starting point of these processes has varied widely. They may be oil from soya beans or, as in another case, lactic acid (a by-product of the manufacture of casein from milk). To date insufficient data are available both as to the manufacture of these compounds and their possible use as rubber substitutes to warrant our relying upon them for a significant part in our immediate rubber program. The inadequacy of our present stockpile of natural rubber for a long war and the need for an early production of synthetics to supplement that stockpile make it imperative that we turn to those substances from which production in substantial amounts before the end of 1943 seems best assured.

Nevertheless one of these relatively untried substances may prove to have important uses either for recapping or for the manufacture of tires or for substitution in other rubber products. Therefore experimentation in and adequate testing of all such substances and of others which should be developed should be encouraged. At the same time it is to be hoped that extravagant claims as to the merits of such pro-substances can be kept out of the public press until full data for a competent evaluation are available.

It must be remembered by the public that a complicated series of chemical reactions are involved in the manufacture of any rubber-like substance from common raw materials. Each step requires long experimentation, protracted engineering study, and the time for construction. Some day it may be possible to prepare a rubber substitute with a less elaborate procedure than now used for the manufacture of butadiene or Neoprene, but it is not within the range of prudence to count upon any such process to yield significant quantities of rubber substitutes within the next two years for military purposes, nor can




Hungry steel mills don't win wars. It takes enormous tonnages of scrap to meet war production goals—140,000 tons of scrap must be collected every day. That's a lot of old boilers, obsolete machinery, abandoned water-towers, worn-out jigs, patterns and molds. If this scrap isn't obtained quickly, steel production will slow down and the whole war effort be imperiled. If you haven't made a start in the nation-wide salvage drive, get in the scrap today. Get out the "junk" that misses routine collections. Call the nearest junk dealer . . . he'll pay you for it and start your scrap on the way to war . . . and Victory. ALAN WOOD STEEL COMPANY, Conshohocken, Pa.

anyone hope for any similar solution of the civilian tire problem in the same period.

### Synthetic Rubbers

To round out this discussion of the chemistry of synthetic rubber, the differences in the various rubbers produced by these processes might be explained:

**Buna S** is the mainstay of the present synthetic program. It is particularly well adapted as a material for tires, showing wearing qualities as a tire tread material approximately 90 percent of those of crude rubber. With suitable compounding, successful tires in sizes up to 7.00 can be made entirely out of Buna S. In the larger truck heavy duty, and combat sizes a certain amount of natural rubber has thus far been found necessary in the sidewalls and carcasses of the tires.

On the basis of presently developed art it seems safe to state that not over 20 percent of the entire weight of a heavy duty Buna S tire would have to be crude rubber. The tire industry believes that this percentage may be reduced to 10 percent, perhaps lower.

Buna S has about the same density as natural rubber and can be vulcanized with sulfur, zinc oxide, and regular accelerators. It requires a plasticizer to facilitate processing. Buna S is an excellent material for the insulation of wires subjected to very rough usage, provided it is covered with a layer of some better weather-resistant material such as Neoprene.

**Neoprene** is the synthetic material most nearly similar in its general utility to natural rubber, although its density is about one third greater. It is more oil-resistant than natural rubber and has good aging properties and can be vulcanized with metallic oxides, with sulfur acting as an accelerator. Neoprene is excellent for heavy duty tires, being the approximate equivalent of natural rubber in ordinary service and definitely superior to natural rubber when run over ground containing flinty or other sharp materials likely to damage the tires.

**Butyl** has inferior abrasive qualities to Buna S or Neoprene but is characterized by a very high degree of impermeability to air and other gases. It has excellent properties for electrical insulation and heat resistance and requires a relatively high temperature for vulcanization with sulfur, zinc oxide, and accelerators. It is only recently that means have been found to attach Butyl to natural rubber or to Buna S or Neoprene, because of the very different degrees of saturation of the constituent carbon atoms. For this reason its use in tires was until recently considered only possible for whole tires but it now appears that it may prove capable of being used as a recapping material also.

**Flexon** is chemically similar to Butyl and differs in that it can be produced at dry ice temperatures simply by mixing the constituents in an open vat. In its production, however, about half of the isobutylene is lost. Isobutylene is a valuable constituent for making aviation gasoline. Also, because of its method of preparation, Flexon is inferior to Butyl, apparently because of lack of homogeneity. It is probable that its quality will be considerably improved with further developments in the art of its production. In general, it can be considered to be an inferior type of Butyl but one which can be produced with a minimum of critical materials in the production plant.

**Thiokol** is brought into the program principally for two reasons: first, because it is quickly producible material for recapping natural rubber tires, and second, because it is exceedingly resistant to oils and various other chemicals which attack natural rubber. Thiokol has an unpleasant odor and produces somewhat the effect of tear gas, though in recent forms of Thiokol this objectionable feature has been considerably reduced. As a recapping material its wearing qualities are definitely inferior to Butyl and about equal to the present types of reclaimed rubber.

### Speed Important

In all of these synthetic materials an important consideration is the speed with which they can be processed in the various operations of milling, mixing, compounding, tire building, and vulcanizing, since on this speed depends the capacity of the rubber milling equipment to handle these materials. The accompanying chart gives the general status of these synthetic materials as of the time when the committee's report was written. It should be emphasized, however, that very rapid developments are being made in the processing arts so that it is reasonable to expect that the situation as regards manufacturing efficiency may be more favorable six months from now.

Here follows a chart comparing various synthetics and reclaimed rubber with crude rubber as a tire and recap material.

*A reproduction from an actual unretouched color photograph which illustrates the appearance of the gauge glass from directly in front.*

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## Committee Predicts Further Shortage

Shortage of 50,000 barrels of petroleum products daily over the next three months for the Atlantic Seaboard is in prospect, according to a report of the committee on petroleum economics to the Petroleum Industries War Council, whose November meeting was held in Chicago. This prospect and analysis of the economics of the industry east of the Rocky Mountains was offered along with recommendations for transmissal to the Office of Petroleum Coordinator for War.

The 50,000 barrels was offered as a minimum with 100,000 barrels daily in prospect if tank car shipments can not be increased beyond an average of 750,000 barrels daily.

As a solution the committee, assuming that fuel-oil rationing cannot be further reduced, suggested either a reduction in gasoline or an increase in tanker shipments from the Gulf Coast. The latter is not within the scope of this committee.

For a longer range, the report was: "After March 31, 1943, estimated supplies for the Eastern Seaboard exceed rationed requirements because of seasonal recessions in demand, coupled with added transportation facilities, particularly those connected with the extension of the War Emergency Pipe Line to the East Coast. These excesses over rationed demand will be available for export movement. If such shipments absorb the surplus indicated, no relaxation of rationing restrictions will be possible."

Because of the influence of rationing of gasoline on a nation-wide basis in December, the report also dealt with its effect on refinery yields, since reduced gasoline consumption will under existing conditions leave a surplus of gasoline. Readjustment of refinery yields was recommended as the solution.

The council passed a resolution in favor of increasing the working week from 40 to 48 hours, and one in opposition to a subsidy from government as a stimulation for wildcat drilling, which was part of its position in favor of a higher price as stimulation for seeking more reserves.

## Dr. Robert E. Wilson Gets Chemists Honor

Dr. Robert E. Wilson, president of Pan American Petroleum & Transport Company, New York, will receive the Perkin medal for 1943. The award is made anually by the Society of Chemical Industry. Selection of the recipient is by a committee of that organization, the American Chemical Society, American Institute of Chemical Engineers, the Electrochemical Society and the Societe de Chemic Industrielle.

The presentation will be made January 8 at a joint meeting of the five societies at the Chemists' Club in New York.

Dr. Wilson has been connected with the petroleum industry since 1922 when he became director of research for Standard Oil Company (Indiana). He was graduated from Wooster College, Wooster, Ohio, in 1914, after which he did two years of advance work in chemical engineering at Massachusetts Institute of Technology. After service in chemical warfare in the first World War he returned to M. I. T. as director of the research laboratory of applied chemistry and later became associate professor of chemical engineering.

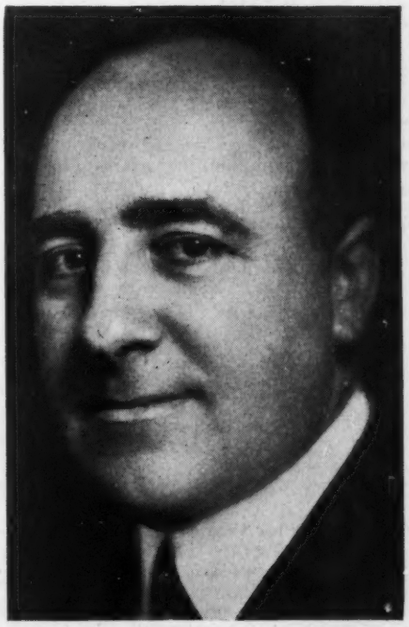
## THE LOOK BOX

After seven years as director of research for Standard Oil Company (Indiana) he was placed in charge of the development and patent department of the company. In 1931 he became a director and in 1933 was elected a vice president.

In January 1935 he became vice president of Pan American Petroleum & Transport Company and in 1937 he was elected president of that company and its subsidiary, American Oil Company.

From June 1940 until August 1941 he was chief petroleum consultant to the Advisory Commission of the Council of National Defense and its successor, the Office of Production Management. Since then he has been a member of the Petroleum Industry War Council and chairman of its committee on petroleum economics. In March, 1942, he became one of the four managing directors of the General Aniline and Film Corporation, which was taken over from German ownership.

He is a member of the Corporation of Massachusetts Institute of Technology and a trustee of the College of Wooster. He is a director of the American Chemical Society and a member of eight scientific organizations.



DR. ROBERT E. WILSON

## Ipatieff Honored by Chicago Chemists

Professor Vladimir Ipatieff and his wife were guests of honor at a banquet of the Chicago chapter, American Institute of Chemists, November 20. The occasion was in celebration of his seventy-fifth birthday, his 50 years in chemistry as well as the golden wedding anniversary.

Dr. Gustav Egloff, director of research, Universal Oil Products Company, introduced Dr. Vanderveer Vorhees, Standard Oil Company (Indiana), who was toastmaster.

Professor Frank Whitmore, Pennsylvania State College, spoke on "Ipatieff—His Influence on World Chemistry." Professor Ipatieff responded with "My Twelve Years in the U. S. A." Dr. Egloff spoke on "Ipatieff's Influence on Industry." Professor Ward W. Evans, Northwestern University, had the subject, "Ipatieff, the Scholar."

Professor Ipatieff, now director of chemical research at Universal Oil Products Company, was born in Russia and in World War I was a general in the Czar's army in charge of chemical activities. He became a citizen of the United States as soon as he was eligible after coming to this country.

## Technical Staff Named By Rubber Director

William M. Jeffers, rubber director, has named a technical staff, which will supervise phases of the synthetic rubber program.

Dr. R. P. Dinsmore, manager of development of The Goodyear Tire & Rubber Company, is one of the selections. He has done extensive research in the development of synthetic-rubber products and is the author of numerous technical papers on both natural and synthetic rubber. One of his recent contributions was in the War Products issue of PETROLEUM REFINER, wherein he dealt with compounding of ingredients into latex.

A chemist with experience in refining processes, Dr. E. R. Gilliland of Massachusetts Institute of Technology, is another member of the staff.

Other members are: E. B. Babcock, chemist for Firestone Tire & Rubber Company, Akron; L. D. Tompkins, Wilton, Connecticut, vice president of United States Rubber Company; W. L. Campbell, New York, vice president of American Machine Defense Corporation; Morehead Patterson, New York, president of American Machine & Foundry Company.

## WPRA Schedules Two December Meetings

Two technical meetings of Western Petroleum Refiners Association will be held during December, one at Tulsa, December 4 and one at Shreveport, December 11.

At Tulsa, H. W. Boggess, Sinclair Refining Company, Tulsa, will discuss "Saving Manpower for War Power."

The meeting at Shreveport will be devoted to a discussion of protection of plant facilities in wartime. Lt. Col. Paul G. Bell and Capt. John M. Mettenheimer, continuous security branch, Eighth Service Command, Fort Sam Houston, will be the speakers.

# Speakers Before API Praise Free Enterprise Status

While carrying through a program based largely on keeping the petroleum industry in step with the war program, the American Petroleum Institute at its Twenty-Third Annual Meeting in the Palmer House, Chicago, November 9, 10, 11 and 12, maintained its position that it be left in peacetime as a free enterprise.

Its position was bolstered by both Harold L. Ickes, Petroleum Coordinator for War, and Ralph K. Davies, deputy coordinator, who expressed opinions that restrictions now imposed as methods of prosecuting the war be relaxed with the end of hostilities.

The institute reelected all officials, passed resolutions in favor of extending the working week to 48 hours and against subsidies as a means of stimulating the search for reserves and against higher gasoline taxes. The annual meeting for 1943 was set for the Palmer House, Chicago, November 8-11. This was decided by the executive committee, which has under advisement the question of the semi-annual meeting.

Coordinator Ickes made a clear-cut statement in favor of free enterprise in a paper, read by Alton W. Jones, president of Cities Service Oil Company, in the absence of the coordinator, as follows:

"But it just so happens, in spite of what has been said to the contrary, that I believe in the American system of free enterprise. It just happens that I also believe that oil can best do its part in wartime with the least possible direction, and the least possible interference by the government."

His observation over the prospect of the pooling of marketing facilities brought an expression of concern over the smaller units within the petroleum industry. On this he said:

"Now your industry is in process of taking the most revolutionary step of all, the abandonment of the hard-hitting, prodigal practices of peacetime free competition and the inauguration of a far-reaching program of what might be called 'unitization' of industry operations. This means that competing companies will share or jointly use many of their facilities and resources, including their transportation terminals. It unavoidably will mean a submergence of individual identities at many points for the duration of the war.

"This is not an adventure which either the oil industry or the Office of the Petroleum Coordinator view with happiness. It is, nevertheless, a step which both your industry and my office recognize as an inescapable consequence of the shortages in materials and manpower which war has created. In fact, even more striking to my mind, is the fact that the industry is doing it voluntarily. You are starting out on this uninviting experience—not because you were arbitrarily ordered to do so—but because your representatives and ours sat down together and decided that it was the course that had to be followed in the light of the realities of war and our determination upon victory.

"At the last meeting of the Petroleum Industry War Council this subject was discussed fully and frankly. It was thoroughly recognized by the Office of the Petroleum Coordinator, as it was by industry representatives, that some of the practices of our properly cherished system of free competition would be suspended under any program calling for joint use of facilities. But I wonder if there is not greater potential danger to the possible permanent loss of competitors than there is in the temporary minimizing of competition. To put it another way, I am more worried, from the long range viewpoint, about what is going to happen to the little fellow during this war than I am about whether the filling station dealer sells Koolmotor out of an Esso pump or vice versa.

"But I don't want to be understood, in saying this, as suggesting that I do not realize the problems that beset the larger, stronger operators, or that I lack sympathy with these operators. I simply mean to say that the peril to the small operator seems to me to be more immediate and his chance for survival more dubious.

"Of course, the essential quality of war is destruction—in the field, destruction of the enemy; at home, the destruction or loss of many things to which we have attached high values. Yet this destruction, paradoxically, is the means of preservation—preservation of the right to continue in what we know and cherish as our way of life. One of the zealously-guarded privileges of that way of life is the right of business men to compete, or if you will, the right of free enterprise. Now, of course I am familiar with the threadbare expression 'we are at war.' I am aware that it appears to be inevitable that the dislocations of this war will result in casualties in the oil industry, just as in other industries. I know, as everyone does, that the ever-mounting drain upon materials and manpower makes such consequences unavoidable. But the point that I should like to make—and the plea I make to you men, especially those of you who represent the stronger elements of the industry, is this: let us not just stand idly by and allow casualties to occur if there is any way, without hampering the prosecution of the war, to prevent them from occurring."

Although Deputy Coordinator Davies dealt chiefly with production and the need for stimulating crude-oil reserves, his views on relationship between the government and the industry were in line with other expressions. On this he said: "We in the Office of Petroleum Coordinator for War see no necessity for governmental entry into the oil business. Time enough for that when private industry has failed to discharge adequately its responsibility to the nation. As to the practicality of the subsidy ideas that have so far been advanced, we are skeptical though ready to give the fullest consideration to any proposal that promises a reasonable solution.

### Price Situation

"The price incentive, we know, has a history to support it. Yet, in a controlled economy such as we have today, it is not the simple treatment it sounds Traced from production through refining and marketing branches and considered in proper relation to the economy as a whole it presents about as complex a problem as can be imagined.

"Then there is more to the question of price than the need for stimulating exploration. The changed and changing costs of operation, capital requirements, and tax provisions all have significant bearing. At the moment I am not prepared to say more than that our office has made a special provision for the study of this price proposal with a view to presenting our position to the price administrator at the earliest possible date."

Attitude of the petroleum industry was expressed by William R. Boyd, Jr., president of the institute, whose annual address contained this:

"We are engaged in an all-out war testing whether this nation, with all its rights and privileges for the individual, can survive. So, while we are exposed to dangers from without we must submit to the application of many drastic rules and regulations that in time of peace we abhor and against which we would rebel in righteous indignation. We submit with some degree of cheerfulness, but altogether with patriotic passions that we may prevent convulsions of disunity within our ranks.

"The right of our own industry to survive this war period and have restored to us thereafter our right to function as a free enterprise in the accustomed way depends upon the degree of our unity and services, but it depends too upon our ability to provide and follow industrial leadership. Thus far we have met every test.

"For our industry we ask no special privileges. We do hold that men are never so apt to settle a question or problem rightly as when they are permitted to discuss it freely. Fortunately for us, this completely synchronized with the policy of the Petroleum Coordinator and his deputy. As for any other agency of the government having to do with any part of our destiny, we ask that it be not deaf to the voice of justice and that it cooperate with us to prevent any impact of the war from crippling our efficiency or our ability to do the job assigned to us."

Boyd reviewed the record of the industry during eleven months of war of which he concluded, "Thus far we have delivered the goods."

The long controversy as to the source of butadiene for the making of synthetic rubber was explained in his speech, as follows:

"The industry was widely subjected

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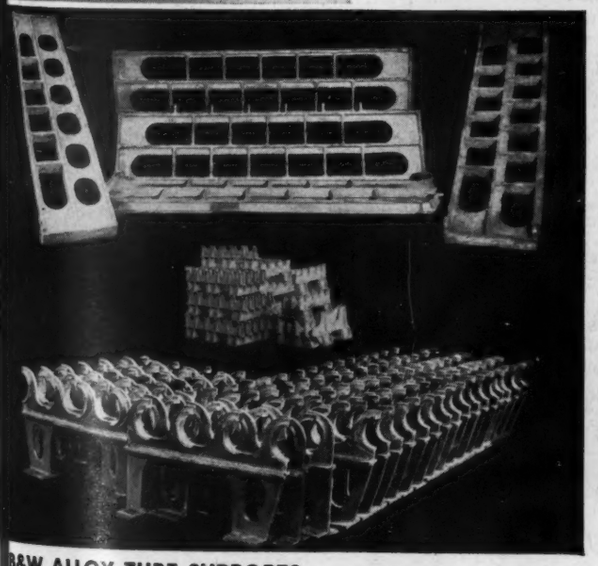

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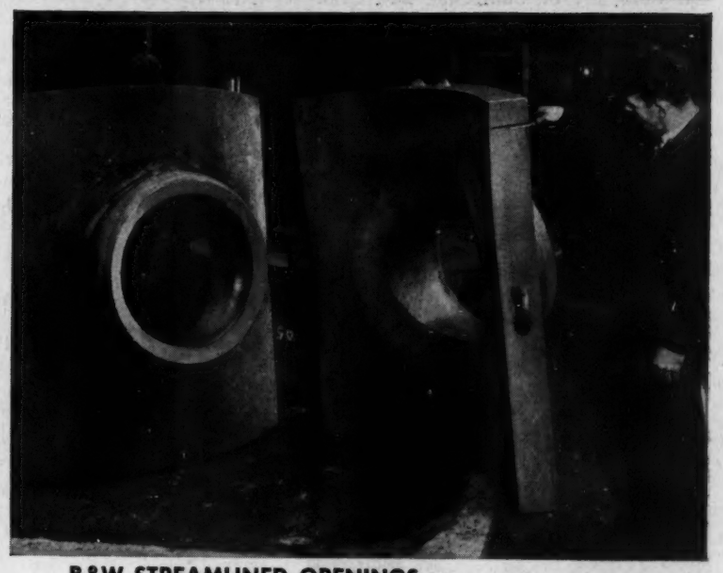

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at one time to the charge of attempts to monopolize the production of material for the manufacture of synthetic rubber to the exclusion of grain alcohol as a source of supply for butadiene. The simple truth is that in the early stages of the synthetic rubber program of the government, only a few petroleum units had developed a formula and the 'know how' for making synthetic rubber and even those units only had pilot plants and small commercial units when the desperate need for rubber was first recognized. Because of this the agencies of government charged with the responsibility for finding new sources of rubber quite naturally turned first to places where the processes and the raw products for obtaining butadiene were known to be available."

# All API Officials Are Reelected At Chicago

William R. Boyd, Jr., president, and all other officers of the American Petroleum Institute were re-elected by the board of directors at the Institute's 23rd annual meeting at Chicago. Members of the Institute elected 48 to the board of directors, and the board itself elected 11 directors. The executive and membership committees of the board, and the Institute's American Petroleum Industries Committee also were re-elected.

In addition to Boyd, the reelected officers are: George A. Hill, Jr., Houston Oil Company of Texas, Houston, vice president for production; J. Howard Pew, Sun Oil Company, Philadelphia, vice president for refining; E. V. Weber, Eureka Oil Company, Cincinnati, vice president for marketing; O. D. Donnell, The Ohio Oil Company, Findlay, Ohio, treasurer; and Lacey Walker, American Petroleum Institute, New York, secretary and assistant treasurer.

The 48 members of the board, nominated by the board of councillors and elected by the membership, are: Production group, Pacific Coast: Dana Hogan, Hogan Petroleum Company, Los Angeles; R. C. Stoner, Standard Oil Company of California, San Francisco; and W. C. Whaley, Barnsdall Oil Company, Los Angeles; Central United States: J. S. Bridwell, Bridwell Oil Company, Wichita Falls, Texas; Amon Carter, Star Telegram, Fort Worth; E. De Golyer, Dallas, Texas; H. L. Hunt, Hunt Oil Company, Dallas; C. P. McGaha, Fain & McGaha, Wichita Falls, Texas; E. H. Salrin, Tide Water Associated Oil Company, Houston; and E. L. Smith, Dallas; Eastern United States: O. D. Donnell, The Ohio Oil Company, Findlay, Ohio; and F. A. Leovy, Gulf Oil Corporation, Pittsburgh.

Refining group, Pacific Coast: S. Belither, Shell Oil Company, Inc., San Francisco; and W. L. Stewart, Union Oil Company of California, Los Angeles; Central United States: C. M. Boggs, The Kanotex Refining Company, Arkansas City, Kansas; C. L. Henderson, Vickers Petroleum Company, Wichita, Kansas; and Roy B. Jones, Panhandle Producing & Refining Company, Wichita Falls, Texas; Eastern United States: Paul G. Blazer, Ashland Refiing Company, Ashland, Kentucky; Harry Logan, United Refining Company, Warren, Pennsylvania; and Charles L. Suhr, The Pennzoil Company, Oil City, Pennsylvania.

Marketing group, Pacific Coast: Reese H. Taylor, Union Oil Company of California, Los Angeles; Central United States: K. S. Adams, Phillips Petroleum Company, Bartlesville, Oklahoma; B. L. Majewski, Deep Rock Oil Corporation, Chicago; and W. G. Skelly, Skelly Oil Company, Tulsa; Eastern United States: C. E. Arnott, Socony-Vacuum Oil Company, Inc., New York; W. V. Hartmann, Gulf Refining Company, Pittsburgh; and W. E. Smith, Standard Oil Company (Kentucky), Louisville, Kentucky.

Transportation group, Pipe Lines: E. J. Henry, The Atlantic Refining Company, Philadelphia; and Harry Moreland, Great Lakes Pipe Line Company, Kansas City; Tank cars: L. J. Drake, Union Tank Car Company, Chicago.

Supply group: Guy Tompson, Bethlehem Supply Company, Tulsa; Ferd Spang, Spang & Company, Butler, Pennsylvania; and A. E. Walker, National Supply Company, Pittsburgh.

Natural gas group: J. D. Creveling, Panhandle Eastern Pipe Line Company, New York.

Natural gasoline group: W. K. Warren, Warren Petroleum Corporation, Tulsa.

At large group: J. A. Brown, Socony-Vacuum Oil Company, New York; Frank Buttram, Buttram Petroleum Company, Oklahoma City; Jacob France, Mid-Continent Petroleum Corporation, Baltimore; Wirt Franklin, Franklin Petroleum Corporation, Ardmore, Oklahoma; H. D. Frueauff, Cities Service Company, New York; S. A. Guiberson, Jr., Guiberson Oil Company, Dallas; J. C. Hunter, Mid-Continent Oil & Gas Association, Abilene, Texas; A. C. Mattei, Honolulu Oil Corporation, San Francisco; A. W. Peake, Standard Oil Company (Indiana), Chicago; Charles F. Roeser, Roeser & Pendleton, Fort Worth; R. van der Woude, Shell Union Oil Corporation, New York; Earle W. Webb, Ethyl Gasoline Corporation, New York; and Eric V. Weber, Eureka Oil Company, Cincinnati.

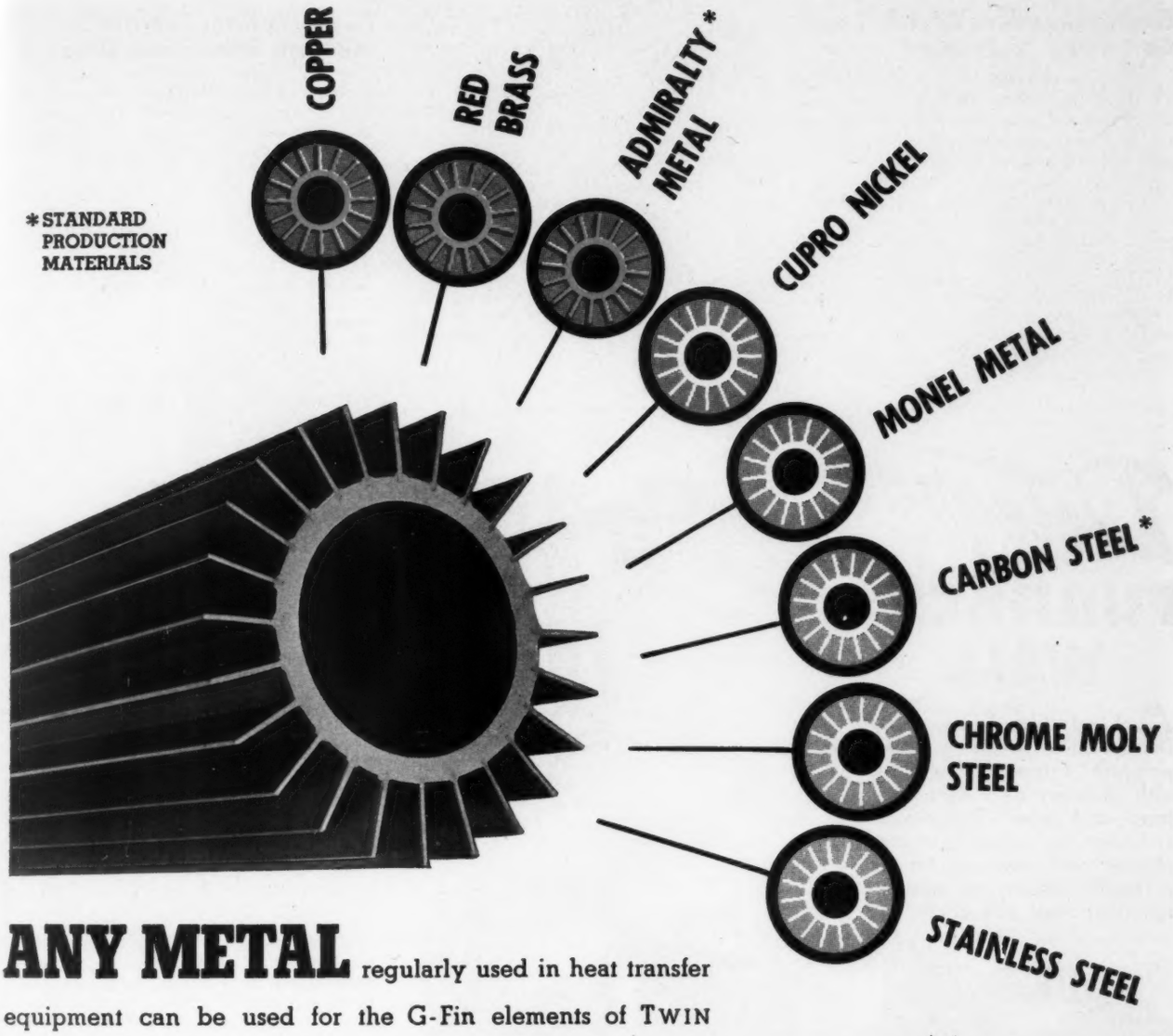
Forty-two of the directors were reelected. The others replaced 1942 members, as follows: Whaley succeeds R. A. Broomfield; Stoner, L. P. St. Clair; Tompson, J. A. Crawford; Spang, W. L. Childs (deceased); Peake, C. J. Barkdull; and Mattei, William N. Davis.

The 11 members elected by the board are: William Bell, Bell Brothers, Robinson, Illinois; Arthur F. Corwin, Socony-Vacuum Oil Company, Inc., New York; H. R. Gallagher, Woodside, California; H. N. Greis, Deep Rock Oil Corporation, Tulsa; Walter S. Hallanan, Plymouth Oil Company, Pittsburgh; Lindsay Hanna, Standard Oil Company of California, San Francisco; Ralph B. Lloyd, Lloyd Corporation, Los Angeles; Parker Melvin, Towne-Melvin Oil Company, Bradford, Pennsylvania; R. W. McDowell, Mid-Continent Petroleum Corporation, Tulsa; Henry D. Moyle, Wasatch Refining Company, Salt Lake City; and Robert E. Wilson, Pan American Petroleum & Transport Company, New York.

Five members were relected. Those elected to succeed others are: Hanna, to succeed Ralph K. Davies; Wilson, J. D. Collett (deceased); Corwin, to fill the unexpired term of E. R. Brown (deceased); Greis, E. H. Moore, resigned; Moyle, T. A. Dines, resigned; and Hallanan, Ralph T. Zook, resigned.

**WM. R. BOYD**
**President American Petroleum Institute**

**J. HOWARD PEW**
**Vice President, Division of Refining**

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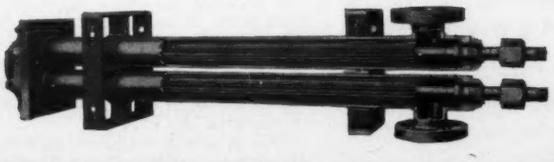

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## Electrochemical Division on Corrosion Is Formed

At its fall meeting in Detroit October 9 the Electrochemical Society formed a division of corrosion. A change in the by-laws to provide for its organization was followed by officials of the new division as follows: chairman, L. G. Vande Bogart, research and development laboratory of The Crane Company, Chicago; vice chairman, H. H. Uhlig, research laboratory of General Electric Company, Schenectady, New York; secretary-treasurer, R. H. Brown, metallurgical division, aluminum research laboratories, Aluminum Company of America, New Kensington, Pennsylvania.

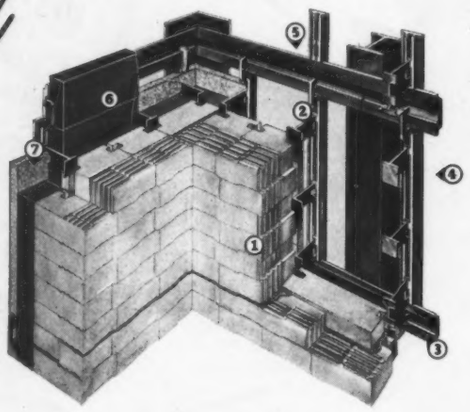
Announcement of the division included the following statement:

The corrosion division was organized because of the interest displayed by a large number of the members of The Electrochemical Society in this phase of the work. The object of the division is to coordinate the interests of the society relating to corrosion, with individuals and organizations which are particularly interested and active in this field, to solicit papers and plan symposia. Members of the society interested in corrosion are eligible for membership in the corrosion division. Persons who are not members, but are particularly interested in corrosion work, are invited to join The Electrochemical Society and participate in the work of the corrosion division.


Detegral

FURNACE WALL

AN advanced design by Detrick for enclosing high temperature furnace conditions, with economy of weight, material and labor. This design embodies the principle of employing each material for its particular quality so that it functions most effectively.



LINKED TOGETHER IN A SINGLE UNIT

*Each material is employed for maximum effectiveness with minimum cost and weight.*

By close integration of the four elements in this wall a new high in efficiency is achieved . . . The heavy refractory face (1) for protection against severe furnace conditions; the high temperature block insulation (6) backing up the refractory stops loss of heat; the light castings (2-3-4-5) hold the wall tightly with a minimum of weight, and the casing (7), applied with a trowel, provides a hard, weatherproof finish — more effective than steel.

Be sure to learn about this new construction from our catalog showing application to all types of boilers, oil heaters, etc.

M. H. DETRICK COMPANY

140 South Dearborn St. Chicago, Ill.

DETRICK FURNACE ENCLOSURES


## R. L. Blaffer, Former Humble Executive, Dies

R. L. Blaffer, one of the founders of Humble Oil & Refining Company, died in Toronto, Canada, October 22. He had retired as chairman of the board in 1941, having previously served as president and treasurer of the company.

Blaffer came to Texas in 1902 when oil development along the Gulf Coast was centered at Spindletop. The next year he and W. S. Farish, now president of Standard Oil Company of New Jersey, formed a partnership. Later R. S. Sterling joined the partnership. Properties developed later were combined in formation of Humble Oil Company. Still later the name was changed to Humble Oil & Refining Company.

He was a native of New Orleans and was graduated from Tulane University in that city.

## As the Coordinator Sees Cooperation

How the petroleum industry and agencies of government have worked together in furthering production of essential war products from petroleum was outlined by Harold L. Ickes, Petroleum Coordinator, before the Baltimore Advertising Club. His speech later was offered by William P. Cole, Jr., then a member of the House of Representatives from Maryland, for inclusion in the Congressional Record.

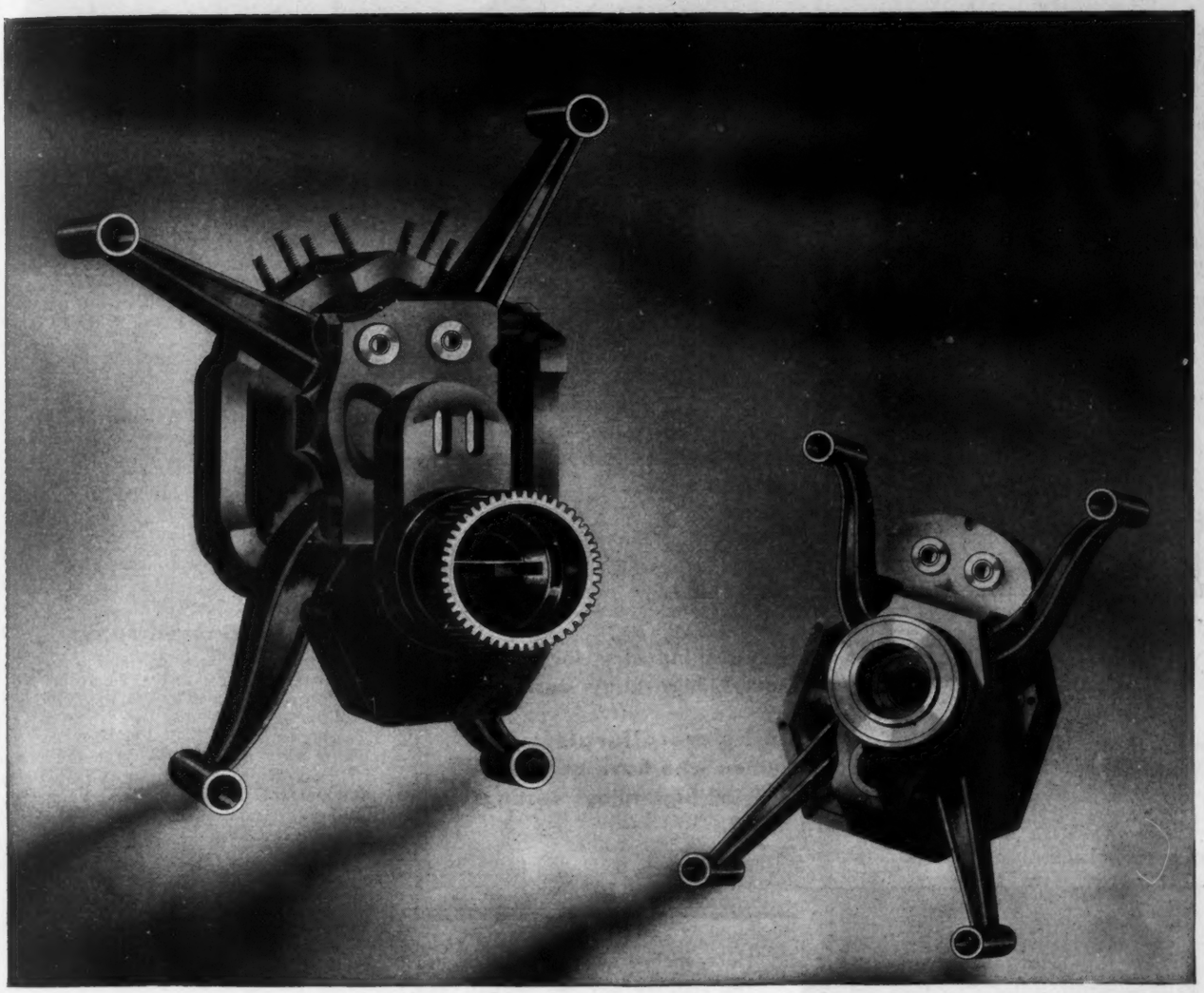
The Coordinator gave a history of the setting up of his agency and its objectives. He paid the petroleum industry high compliment for its attitude and accomplishments. Parts of his speech dealing with these subjects follow:

"In terms of human relationship the machinery that I have been talking about might be called cooperation. The Office of Petroleum Coordinator for War and the oil industry have been working together in close and cordial understanding from the beginning, and every day the tie grows stronger. Nothing of the sort had ever been attempted before, at least on the scale on which we operate. So far as I know, it is a unique arrangement and one which has convincingly demonstrated its effectiveness.

"The Office of Petroleum Coordinator does not take any major action, or adopt any major policy, without first submitting it to the industry representatives for their study and advice. As a matter of fact, in more cases than not we hand our problems directly to the industry and ask it to give us the answer. Although the final determination is and properly must be that of the government, it is very seldom that a mutually satisfactory agreement is not reached. We have arguments now and then—good ones. It wouldn't be any fun otherwise. The point that I want to make is that we argue out our differences openly and frankly. When it's over, everybody understands one another and we go ahead with the job.

"All of you have heard and read about 100-octane aviation gasoline—that superlative fuel that contains within it the molecules of speed, power, and maneuverability that have contributed so important a part to the brilliant victories of our Army, Navy, and Marine fliers at Midway Island, in the Coral Sea, and in the Solomons.

"A year ago we were making only about 40,000 barrels of this precious fuel



# why TUESDAY couldn't marry THURSDAY

It happened in an airplane factory.

When brought together on the assembly line, some close-tolerance motor parts did not fit. Yet each part had been made correctly.

One part had been made on Tuesday—accurately. The other part had been made on Thursday—also accurately.

But Thursday was a warmer day than Tuesday. Uncontrolled expansion, due to the difference in temperature, upset the microscopically close tolerances of the two parts . . . thus preventing an accurate fit.

To eliminate the resulting waste and delay . . . air conditioning was installed to keep temperatures *under control.* It had to be extremely efficient air conditioning—with more *exact* temperature and humidity. *Precision* air conditioning—the kind General Electric is installing in many war production plants.

Today, air conditioning is making enormous, revolutionary advances in meeting stringent wartime requirements. After the war, the lessons learned in making fighting equipment will be applied to bring many new and interesting benefits to the general public.

More people will enjoy air conditioning . . . in homes . . . in cars . . . and in ever-increasing numbers of stores, offices and factories. It will be vastly improved air conditioning . . . in many ways. Temperature *and humidity* will be maintained more exactly than ever before. Equipment will be compact . . . flexible . . . economical.

Today, hundreds of wartime industrial users are turning to General Electric for reliable equipment. In the future, G-E air conditioning will fill the needs of all kinds of users.

*Air Conditioning and Commercial Refrigeration Department, Division 423, General Electric Co., Bloomfield, N. J.*

*Air Conditioning by*

**GENERAL ELECTRIC**

daily, with just a handful of refiners even knowing how to make it. Quickly, the technical experts on my staff went to work on the problem, surveying refineries throughout the land, scrutinizing methods, analyzing possibilities. They came up for air with a lot of answers, but it was plain that they were going to play havoc with normal competitive considerations.

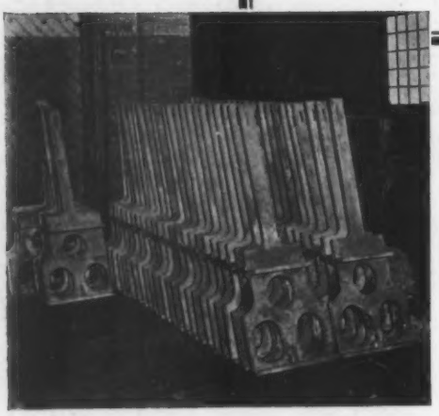
"Nevertheless, we took our proposals to the industry. We told it what we wanted it to do; showed it what its country needed. Quickly the industry gave its answer. The owners of patents slashed their royalty rates. The refiners pooled their patents, their knowledge, their facilities, their raw materials, their products. They put their own experts to work on the problem of increasing production from existing plants, improving methods, getting new plants under way. I only wish that I had the time to give you some comprehension of the enormity and complexity of the job that was done. I will say this: The production of 100-octane gasoline today is far beyond what anyone had believed even remotely possible a year ago, and the additional facilities now under construction will give Herr Schickelgruber the worst headache that he has ever had.

"We can find satisfaction in the fact that the program has been so planned that the little refiners have been brought into the program, and so that the taxpayers also save many millions of dollars every year because of the favorable prices negotiated by members of our staff."

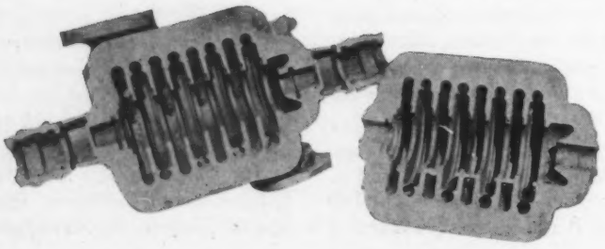

DURALOY

. . . serving your industry for years with sound high-alloy castings.

. . . staffed by metallurgists and foundrymen who have been specializing in high-alloy castings since 1922.



Here, in two short sentences, are two reasons why you should send your chrome-iron or chrome-nickel casting requirements to Duraloy. And, if your operating conditions pose a puzzling problem as to the selection of alloying elements, our twenty years of experience will be invaluable. Our metallurgists know refinery requirements. Our foundrymen know how to produce the sound, high-alloy castings.



THE DURALOY COMPANY

OFFICE AND PLANT: SCOTTDALE, PA.

Eastern Office: 12 East 41st St., New York, N. Y.

Los Angeles: Great Western Steel Company

Detroit: The Duraloy Co. of Detroit — Scranton, Pa.: Coffin & Smith

Metal Goods Corporation: St. Louis — Houston — Dallas — Tulsa — New Orleans

11-DU-3


## Refiners Conclude Two Technical Meetings

Wichita and Shreveport drew the two 1942 regional technical meetings of Western Petroleum Refiners Association, the first being held October 9 and the latter October 30.

At Wichita the program consisted of a paper by Dr. Frank H. Dotterweich, Office of Petroleum Coordinator, "The Importance of Natural Gasoline and Its Derivatives to the Synthetic Rubber and Aviation Gasoline Programs," Arch L. Foster, Phillips Petroleum Company, "Rubber—Made to Order"; and "Present Day Furnace Designs," H. O. Johanson, M. H. Detrick Company, Tulsa.

The program for the Shreveport meeting brought papers from Joe E. Young, Sr., General Metallizing & Machine Company, "Metallizing in the Refinery," C. G. Kreiger, The Ethyl Corporation, Detroit, "Tractors and Farm Machinery—the Machine Tools of Agriculture"; F. C. Moriarity, Universal Oil Products Company, Chicago, "Mercaptans."

## Chairman Selected For NGAA Committees

Chairmen and vice chairmen for all committees of the Natural Gasoline Association of America have been selected as follows:

Economics, H. E. Felt, Warren Petroleum Company, Tulsa, Henry Clark, J. S. Abercrombie Company, Houston; Gas Contract, G. T. Tennison, Shell Oil Company, Houston, Ralph A. Worley, The Parade Company, Shreveport; Gas Testing, H. L. Oder, Cities Service Oil Company, Bartlesville, R. H. Clark, Phillips Petroleum Company, Bartlesville; Legal, W. J. Holleman, Glen Rose Gasoline Company, Tulsa, H. K. Hudson, Phillips Petroleum Company, Bartlesville; Research and Educational, J. W. Vaiden, Skelly Oil Company, Tulsa, W. L. Bowser, Atlantic Refining Company, Dallas; Specifications and Outage, F. B. Haverfield, Continental Oil Company, Ponca City, Phil D. Baker, Carter Oil Company, Tulsa; Technical, H. H. Beeson, Sabine Valley Gasoline Company, Shreveport, M. R. Church, Shell Oil Company, Houston; Traffic, W. A. Rowsey, Lone Star Gasoline Company, Dallas, W. H. Anders, Coltexo Corporation, Monroe; Divisional, C. R. Williams, The Chicago Corporation, Corpus Christi, J. R. Butler, Cotton Valley Operators Committee, Cotton Valley.

## Big Pipe Line Will Go to Atlantic Coast

Extension of the 24-inch pipe line to the Atlantic seaboard has been authorized by War Production Board. When the present line from Longview, Texas, to Morris City, Illinois, is completed in December, crews will begin work on the extension. At least 300,000 barrels of oil daily will be delivered to the Philadelphia and New York refining areas when the full 1388 miles of the line is in operation.

In commenting on the extension Harold L. Ickes, Petroleum Coordinator, said:

"The oil that this line will deliver to the refineries of the New York-Philadelphia area will benefit not only our war industries, but, more important still, it will make possible the release of many

## *Every Down Stroke a Power Stroke*

The 2-cycle engine was developed to eliminate what was known as the "waste" stroke in 4-cycle operation. In the 2-cycle engine, instead of only half of the piston's down-strokes being power strokes, every down-stroke is a power stroke!

In the perfected CLARK Super-2-Cycle Engine this has resulted in power output also being actually doubled, as compared with the 4-cycle engine of equivalent size and displacement.

In addition to doubled power, the 2-cycle principle as perfected in CLARK "Angle" Compressors, offers these basic advantages:

1. GREATER SIMPLICITY — No intake or exhaust valves.
2. GREATER FUEL ECONOMY—due to Clark patented Fuel Injection.
3. LESS WEAR—as the power is produced with half the number of power cylinders.
4. SMOOTHER OPERATION.
5. FEWER MAN HOURS — due to simple design, few parts, and ease of servicing vertical cylinders.
6. LOWER OIL CONSUMPTION.
7. LOWER INSTALLATION COST—due to shipment assembled, small foundations, small buildings.

These points, explaining the leadership of the CLARK "Angle", merit your thorough investigation. Our engineers are at your service.

CLARK BROS. CO., INC. . . . . .OLEAN, NEW YORK, U. S. A.

Export Offices: 30 Rockefeller Plaza, New York. Domestic Sales Offices and Warehouses: Tulsa, Okla.; Houston, Texas; Chicago, Ill. (122 S. Michigan Ave.); Boston, Mass. (131 Clarendon St.); Huntington Park, Calif. (5715 Bicket St.) Foreign Offices: 72 Turnmill St., E. C. 1, London; Avda Roque Saenz Pena 832, Buenos Aires.

Affiliated Companies: Dresser Mfg. Co., Bradford Pa.; Pacific Pump Works, Huntington Park, Calif.; Bryant Heater Co., Cleveland, Ohio.

CLARK 6-Cylinder 600 H.P. "Super-2-Cycle" Angle Compressor



# CLARK
## *Super-2-Cycle*

**No. 1** OF A SERIES TO HELP YOU KEEP CRACKING STILLS OPERATING AT PEAK EFFICIENCY

**ANNOUNCING A SERIES OF TUBE CLEANING SERVICE HINTS**

In this series of ads we will try to analyze and offer solutions to specific problems that may confront you. We will also show you how tube cleaning equipment can be made to be of maximum service to you. Watch for these ads each month hereafter.

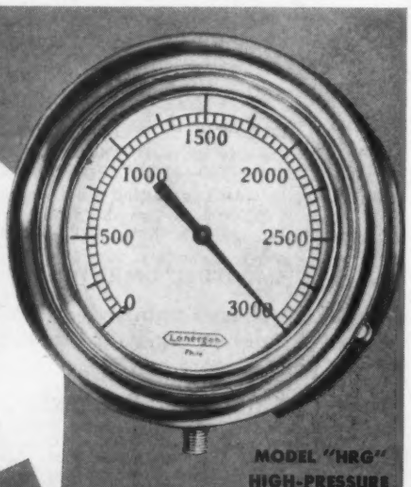
In this first ad, we would like to call attention to our service engineers. They are always available to solve unusual problems in refinery maintenance. In many such cases, our engineers have designed special tools to combat a refinery problem, and these tools have later been made available to the entire industry. Call on Airetool for this service at any time.

**AIRETOOL MANUFACTURING CO.**

SPRINGFIELD, OHIO

*Manufacturers of Tube Cleaners, Tube Expanders and other Refinery specialties.*

Constantly UNDER PRESSURE TO HELP BEAT THE AXIS




MODEL "HRG" HIGH-PRESSURE REFINERY GAUGE

Lonergan

SAFETY AND RELIEF PRESSURE AND VACUUM

**VALVES—GAUGES**

POWER PLANT SPECIALTIES

J. E. LONERGAN CO. 211 RACE ST., PHILA., PA.

REPRESENTATIVES IN HOUSTON, LOS ANGELES, SAN FRANCISCO

ocean-going tank ships from the long water haul from Gulf Coast ports. This fact alone is justification enough for the extension of the line at this time, for it will aid us materially in carrying the war to the enemy. In fact, so important do I regard the function the pipe line can perform in the winning of this war that it is perfectly clear to me that we must not only complete this line with the utmost possible dispatch, but that we must immediately give consideration to the advisability of constructing still another paralleling the first."

## Dr. Leopold Singer Dies in London

Dr. Leopold Singer, who had been on the foreign staff of Universal Oil Products Company since 1926, died in London in June at the age of 73. He was a native of Vienna, who was educated at the Polytechnic of Zurich and the University of Zurich, where he won the degree of Ph.D.

His practical work began at his father's refinery at Orsova, where he instituted scientific methods to replace empirical operation. In 1903 he took charge of Fanto A. G., at that time in Austria. He held the position until 1912 and the plant became the largest and best equipped in Europe at that time. In 1914 he took charge of the lubricating oil plant of the Rhenania Refinery in Duesseldorf.

## Chemical Technology Of Petroleum

This book represents a revision of the earlier work, "Petroleum and Its Products," by William A. Gruse, who with Donald R. Stevens has completed the new work of presenting the chemical discussion of the properties, refining and utilization of petroleum. Of the revision the publisher, McGraw-Hill Book Company, New York, gave this information:

"Every chapter has been rewritten and new chapters have been added on thermodynamics as applied to the problems of hydrocarbon chemistry, production chemistry. A wealth of new material has been included on distillation, physical properties, motor fuels, lubricants, cracking, crude oils and refining of oil stocks."

The authors are with Mellon Institute of Industrial Research. Their book can be had through the book department of The Gulf Publishing Company, P. O. Box 2608, Houston, Texas, price $7.50.

## Exchange Institute Publishes Standards

The Heat Exchange Institute has published a new standard to complement its series on surface and barometric condensers and steam jet ejectors. The new publiction is "Standards of the Non-Deaerating Heater Section."

It contains recommendations on nomenclature, definitions, construction, ratings, accessories and a typical specification. The specification is to assist the designing engineer in furnishing information for construction of the proper unit.

Copies sell for 75 cents and are available through C. C. Rohrbach, secretary, Heat Exchange Institute, 90 West Street, New York.

### Clarification Sought On Consent Decree

In order to clarify its position in the war program Standard Oil Company (N. J.) has asked the United States District Court at Newark, New Jersey, to determine whether its actions under recommendations of the Office of Petroleum Coordinator for War are in keeping with the consent decree in that court last March. The petition seeks an order to that effect. In a second petition the corporation has asked postponement until after the war on the question of whether certain issues regarding catalytic refining processes are subject to provisions of the consent decree.

The petitions have been explained in the following release from the company:

"In its petition the company said that the consent decree enjoined it from carrying to any conclusion certain previous proposals for the licensing and cross-licensing of its catalytic refining patents with others in this same field. However, in July of this year, it points out, the Office of Petroleum Coordinator for War recommended that the following companies negotiate such cross-license and licensing agreements: Standard Oil Development Company, Standard Catalytic Company, Shell Development Company, Texaco Development Company, Standard Oil Company (Indiana), Universal Oil Products Company, The M. W. Kellogg Company and their respective affiliated companies.

"The OPC also recommended that the same companies carry forward their cooperative research and development work on the catalytic cracking process, the catalytic reforming process and related catalytic refining processes. Moreover, it proposed that as such processes became available for commercial use, the design, construction and operation of plants for their use be standardized and that there be made available to the petroleum industry generally all preliminary information and data to enable any petroleum refiner to obtain estimates and bids, as well as any needed information to operate and construct licensed plants. Any cross-licensing and license agreements, however, were not to become operative until approved both by the chief counsel of the OPC and certified by the Chairman of the War Production Board.

"Subsequently, the company said in its petition, the Chairman of the War Production Board, Donald M. Nelson, approved the recommendations of the Office of Petroleum Coordinator for War, following which the recommended agreements were negotiated. The proposed cross license and licensing agreements on these various catalytic refining processes were submitted to the OPC on November 7 last.

"The company has now asked the court to permit it to carry out these agreements, as recommended by the Office of Petroleum Coordinator for War.

"In the second request in its petition the Standard Oil Company (N. J.) said that in the discussions leading up to the consent decree the catalytic cracking process, the most important of all its new oil refining processes, was specifically discussed and both its name and definition were omitted from the con-


For Complete
Steel Pipe and Tube Service
Call
Vinson Supply Company
NATIONAL TUBE PRODUCTS

WALLS WITHOUT WELDS

In meeting the high priority requirements of our customers, VINSON SUPPLY COMPANY has been able to maintain adequate stocks to serve your immediate needs for Refinery Sizes of National Condenser Tubes as well as Standard, Extra-Heavy and Double Extra-Heavy Seamless Pipe. Large OD Seamless is carried in sizes from 14" OD to 24" OD, in several wall thicknesses.

Exclusive Representative throughout the Mid-Continent Area
FISHER
Automatic Controllers
A Fisher Trained Engineer is always available at VINSON SUPPLY COMPANY and six Fisher Engineers travel out of the Tulsa, Dallas and Odessa offices giving a COMPLETE Sales and Installation Service.

Let us also have your requirements on Boiler and Still Tubes. This greater combined Refinery Steel Pipe and Tube facilities of the VINSON SUPPLY COMPANY assures you maximum service with economy.

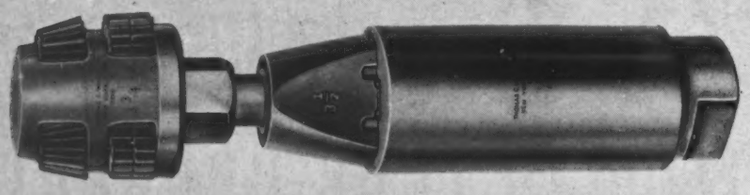
Fast Service

FISHER
Automatic Controllers
NATIONAL
Pipe and Steel Tubes
TUBE-TURNS
Tees, Reducers, Flanges and Welding Caps
CHASE
"Antimonial Admiralty" Condenser Tubes
Standard Brass Products

VINSON SUPPLY COMPANY
TULSA, DALLAS and ODESSA, TEXAS

sent decree. In fact, the company signed the consent decree on the express understanding that its patents relating to catalytic cracking were not intended to be included in the decree. Subsequently, the company points out, a representative of the Attorney General wrote to Standard's counsel and said that 'it is our position that all of the catalytic refining patents are subject to the consent decree.' The company's counsel took issue with this new position.

"Standard explained to the court that the question of whether any facts or circumstances bring the catalytic cracking patents within any general provisions of the consent decree will require presentation and consideration of the whole history of the negotiations between many parties, covering a wide variety of subject matter over a period of three and one half years. The company said that evidence on these issues will require the testimony of its chief technical executives, distracting their time and energy seriously from their duties which are today strictly a part of the war effort. In addition, many of its witnesses are in the armed services or other government war services. Therefore, the company has asked that the determination of this issue be postponed until after the termination of the war. The company states in its petition that during such postponement it will accept the court's conditions for safeguarding the public interest. It expressed its willingness to impound any royalties received on catalytic cracking patents."

DIRTY STILL TUBES ARE ENEMY SABOTEURS

**Now, when *all* refinery equipment must operate at maximum efficiency to produce the enormous quantities of gasoline and other petroleum products for our armed forces and our allies, it is essential that stills be kept on stream as long as possible between cleanings and that down-time be reduced to the minimum. Because dirty still tubes slow up production—while cleaning down-time stops it—they are as dangerous to maximum production as enemy saboteurs.**

**Wilson Tube Cleaners keep stills and other refinery equipment operating at *maximum efficiency* and *for longer periods* between cleanings because they clean *faster* and *better* and thus *reduce* down-time and enable stills to remain on stream *longer* between cleanings.**

**There is a Wilson Tube Cleaner, cutter head or other accessory which *quickly, thoroughly* and *economically* overcomes *any* coke, scale or gum encountered in stills or other refinery equipment.**

**Write for the name of our representative nearest to you or ask for a copy of our NEW forty-page catalog which fully describes and illustrates the complete line of Wilson tube cleaning equipment.**

**INVEST IN AMERICA! BUY WAR BONDS AND STAMPS!**

THOMAS C. WILSON, Inc.
PIPE AND TUBE CLEANERS EXCLUSIVELY
47-28 37th Street Long Island City, N. Y.


## Second Distillate Well Testing Is Completed

Second of the series of tests to determine accepted methods for determining representative samples from the output of distillate wells was completed near Robstown, Texas, October 30. The tests are under sponsorship of the High Pressure Division of the Natural Gasoline Association of America. A well of the Lockhart Corporation, Luling Foundation 1, was used for these tests. The first series of tests was made in April of this year and two others will come later.

The tests are under the general supervision of C. R. Williams, general superintendent of Chicago Corporation, Corpus Christi. Williams is a vice president of the Natural Gasoline Association of America.

Direct supervision of the tests at the Luling well was under W. L. Bowser, The Atlantic Refining Company, Dallas; D. A. Sillers, Lone Star Gas Company, Dallas; J. C. Birdsall, Lockhart Petroleum Corporation, Robstown; T. A. Matthews, Phillips Petroleum Company, Bartlesville; and William F. Lowe, secretary-treasurer of Natural Gasoline Association of America, Tulsa.

Testing laboratories which participated included Jarrett Laboratory, Alice, Texas; Henderson Laboratories, San Antonio; Gas Laboratories, Inc., Houston; E. W. Saybolt & Company, Houston.

Among those present for the test were M. M. Conn, The Atlantic Refining Company, Dallas; Harry Elliott, J. S. Abercrombie Company, Houston; T. W. McGuire, Cotton Valley Operators Committee, Cotton Valley, Louisiana; Horton Pruett, Jess Scarborough, Elmer Ward and J. T. May, Chicago Corporation, Corpus Christi; R. F. Downey and S. M. McAnelly, Lone Star Gasoline Company, Dallas; Lestor Wood, Phillips Petroleum Company, Borger; W. R. Winnington and John Dillon, Shell Oil Company, Houston; J. L. Lee and C. Seekamp, Stanolind Oil & Gas Company, Tulsa; Dr. Frank H. Dotterweich and Emerson Korgas, Texas College of Arts and Industries, Kingsville.

## Shell Plants Set Safety Records

The four natural gasoline plants operated by Shell Oil Company in its Texas-Gulf Area have completed one year of continuous operation, ending August 1, 1942, without a disabling injury. This is a noteworthy achievement in view of the extensive construction programs during this period at the Magnolia, Arkansas, and Wasson, Texas, plants, and the extensive repairs at the Hobbs, New Mexico, plant.

The Iowa, Louisiana, plant, J. L. May, superintendent, has the enviable record of eight straight years of continuous operation without a disabling injury.

The Magnolia plant, C. E. Haines, superintendent, has suffered only two disabling injuries, both of a minor nature, during its 2½ years of operation up to August 1, 1942.

The Wasson plant, S. W. Craig, superintendent, has suffered only one disabling injury from beginning of operations in November, 1939, to August 1, 1942.

The Hobbs plant, T. W. Brown, chief engineer, was taken over by Shell on August 1, 1941, and has suffered no disabling injuries for the year ending August 1, 1942.

### Refining Yields Not Yet in Adjustment

There was only partial success during the week ended November 7 in adjusting refinery operations to the radically changed requirements imposed by scheduled nationwide rationing of gasoline. Production of gasoline was reduced by 37,000 barrels daily from the previous week's rate, with the result that output conformed very closely with current consumption, as evidenced by the fact only 11,000 barrels a day accumulated in storage.

However, that reduction in gasoline production was achieved in considerable part by curbing crude runs to refinery stills, rather than by the recommended lowering of gasoline yields. Daily average crude runs to stills were down by 57,000 barrels from the previous week's rate.

There was achieved an increased refinery yield of urgently needed heating oil, as indicated by the fact that stocks of gas oil and distillate fuel were increased in the satisfactory amount of 903,000 barrels within the 7 days, compared with a build-up of 763,000 barrels the previous week and an increase of about 650,000 barrels in the week ended November 8, 1941. Nevertheless, stocks of the light fuel oils are 7,000,000 barrels or 13 percent smaller now than a year ago, in totaling 49,034,000 barrels (as of November 7).

Less favorable results occurred in the week of November 7 in connection with heavy fuel oils. Stocks of those fuels were further depleted by 849,000 barrels and then were 16,500,000 barrels (17.4 percent) smaller than a year previously in totaling 78,317,000 barrels. All districts of the country are seriously low on inventories of those oils.

Crude runs to stills for the whole United States averaged 3,674,000 barrels daily in the week ended November 7, down 57,000 from the week before, and 321,000 barrels under the daily average runs of 3,995,000 barrels in the corresponding week last year. The nation's refining equipment was being operated at 76.5 percent of capacity. In OPC Districts 1 and 3, Southwest and East Coast areas, plants charged to stills 1,631,000 barrels of crude daily and used 67 percent of capacity. In the Appalachian. Middle Western, and upper Mid-Continent districts, plants utilized 88 to 90 percent of rated capacity, and in California 87 percent, while the Rocky Mountain states used 60 percent. Only the Oklahoma-Kansas runs were higher than in the previous week.

Production of gasoline, similarly, was lower than in the preceding week in all districts except Oklahoma-Kansas. And all districts showed withdrawals of gasoline from storage except the combined East Coast - Southwest districts, now grouped in published statistics. Presumably, the 675,000-barrel piling up of gasoline in the combined districts occurred principally on the Gulf Coast, considering the use of transportation to the East in present large measure for moving fuel oils.

United States stocks of finished and unfinished gasoline totaled 79,238,000 barrels on November 7, up 79,000 from a week earlier but 3,227,000 barrels (4 percent) under the 82,465,000 barrels on hand November 8 last year.

The 704,000 addition to stocks of gas oil and distillate fuel in the week ended


# WHAT YOU SHOULD KNOW ABOUT PIPE HANGERS!

There is no place for guesswork in the selection of Pipe Hangers. The following excerpts from the American Standards Association Code for Pressure Piping give time-proved guidance to correct procedure.

**MALLEABLE IRON CASTINGS** may be used for pipe clamps, beam clamps, hanger flanges, clips and bases, swivel rings and similar parts of pipe supports, but their use shall be limited to such cases where the operating temperature of the pipe line will not be in excess of 450°F.

**STEEL or WROUGHT IRON** can be used throughout for hanger rods, turnbuckles, beam clamps, pipe clamps, supports, rollers, guides and bases.

## GRINNELL offers an ENGINEERED PIPE HANGER

*for each specific service . . .*

**MALLEABLE IRON ADJUSTABLE SWIVEL RING** (Split Ring Type) – Underwriters Approved – Patented. Can be used with coach screw rod or machine threaded rod with practically any type of ceiling flange, expansion case, or insert. Swivel shank allows adjustment. No temporary support of pipe line is needed while making adjustments. Swivel shank locks automatically when pipe is in desired position. The hinging of the ring is off center, providing sufficient seating to hold the pipe before closing the ring.

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November 7 likely occurred mainly in the East Coast district, where needed, as that area and the supplying Southwest together showed a 645,000-barrel increase. There were withdrawals in the Appalachian and Middle Western districts, but Oklahoma-Kansas-Missouri added 101,000 barrels. Rocky Mountain states were virtually unchanged, and California added 37,000.

The week's draft on heavy fuel stocks occurred chiefly in the combined East Coast - Southwest districts, but there were withdrawals also in the Appalachian, Middle Western, and California districts. Only Oklahoma-Kansas-Missouri and the Rocky Mountain districts added to storage.

United States production of crude oil averaged 3,838,000 barrels daily in the week ended November 7, the American Petroleum Institute reported. The output was 63,000 barrels a day lower than in the previous week and 258,000 barrels (6.2 percent) under the 4,096,000-barrel daily average of the week ended November 8, 1941.

Crude oil stocks in the United States previously had been steadily declining, but they increased 1,280,000 barrels to a total of 239,266,000 in the week ended October 31, the Bureau of Mines reported. Nevertheless, the crude inventory of the nation is 4,000,000 barrels (1.6 percent) smaller than a year ago and within 10,000,000 barrels of the lowest point of the past 20 years, reached in October, 1939.

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## Off-the-Record Session On Natural Gasoline

Styled after the fashion of the radio program "Information Please," executives and technologists of the natural gasoline industry held an off-the-record session in Chicago November 10 during a lull in proceedings of the annual meeting of the American Petroleum Institute. Leader for the session was T. R. Goebel, Shell Oil Company, Houston, whose staff of experts consisted of A. J. L. Hutchinson, Fluor Corporation, Los Angeles; Harold Vagthorg, Institute of Gas Technology, Chicago; E. R. Smoley, V. Mekler and V. O. Bowles, The Lummus Company, New York; Louis Weiss, Stearns Roger Manufacturing Corporation, Denver; Henry Wade, Parkhill-Wade, Los Angeles; Gustav Egloff, Louis S. Kassel, J. McAfer and J. F. Walter, Universal Oil Products Company, Chicago.

As assistants in leading the conference Goebel had Dr. G. G. Brown, University of Michigan and C. R. Williams, Chicago Corporation, Corpus Christi.

Presenting the needs of the war program were representatives of the OPC, Natural Gas and Natural Gasoline Division, E. Holley Poe, director; P. M. Raigorodsky, assistant director, and James E. Pew, chief of the natural gasoline section.

The broad question before the meeting was concerned with the best means for stimulating production of the hydrocarbons in the paraffin group most useful in the manufacture of critical war products. With the knowledge that it is one of the chief and most easily available sources of butane, iso-butane and iso-pentane, the industry was seeking information on the best mechanical and economic routes to increase that production. There is full realization that many small plants are not equipped to isolate the individual hydrocarbons but might be changed with the addition of a small amount of critical material to make a 40-pound product which could be split as needed by manufacturers of rubber and aviation fuel. There is also the definite possibility that many plants, with greater facilities and the addition of some equipment, could extract the individual hydrocarbons for marketing as pure raw material for blending or processing to synthetics. Between these two extremes of plant utility are many feasible and practical variations and the entire range was covered in the questions submitted.

Answers of the process experts to these questions and the open forum discussion of them led to several general conclusions of value to the industry. Beginning with the acknowledged fact that iso-butane is currently the most critically needed hydrocarbon in the paraffin group due to war demands, it was concluded this demand would increase rather than diminish for several years to come and that there would be a wide market for it in the post-war era. Every effort should be made to increase iso-butane yield by improving the yield of total butanes but isomerization plants are not feasible at natural gasoline plants having a production of less than 50,000 gallons per day. Central isomerization or alkylation plants fed by the production of several natural gasoline plants are considered a definite possibility.

### Gas Association Elects Officials

Officials of the American Gas Association, elected at the annual meeting in Chicago, October 5 and 6 are:

President, Arthur F. Bridge, vice president, Southern Counties Gas Company, Los Angeles.

Vice president, Ernest R. Acker, president, Central Hudson Gas & Electric Corporation, Poughkeepsie, New York.

Treasurer, J. L. Llewellyn, insurance manager, Brooklyn Union Gas Company, Brooklyn.

Directors for two year terms are: John W. Barten, vice president, Michigan Consolidated Gas Company, Detroit; James A. Brown, Commonwealth & Southern Corporation, New York; D. W. Harris, vice president, Arkansas-Louisiana Gas Company, Shreveport; H. N. Mallon, Dresser Manufacturing Company, Bradford, Pennsylvania; Hudson W. Reed, vice president, Philadelphia Gas Works Company, Philadelphia; W. F. Rockwell, Pittsburgh Equitable Meter Company, Pittsburgh; Herman Russell, president, Rochester Gas & Electric Corporation, Rochester, New York; Marcy L. Sperry, president, Washington Gas Light Company, Washington; T. J. Strickler, vice president, Kansas City Gas Company, Kansas City; P. S. Young, Public Service Electric & Gas Company, Newark, New Jersey; R. G. Bennett, vice president, Portland Gas & Coke Company, Portland, Oregon.

Officials of the Natural Gas Section for 1942-43 are: chairman, Burt B. Bay, Northern Natural Gas Company, Omaha, Nebraska; vice chairman, R. E. Wertz, Amarillo Gas Company, Amarillo, Texas.

### Nazis Kill Noted Polish Technologist

Confirmation of the assassination of Professor Stanislaw Pilat, noted Polish petroleum technologist has come through the Journal of the Institute of Petroleum. This tribute to him is taken from the latest available issue:

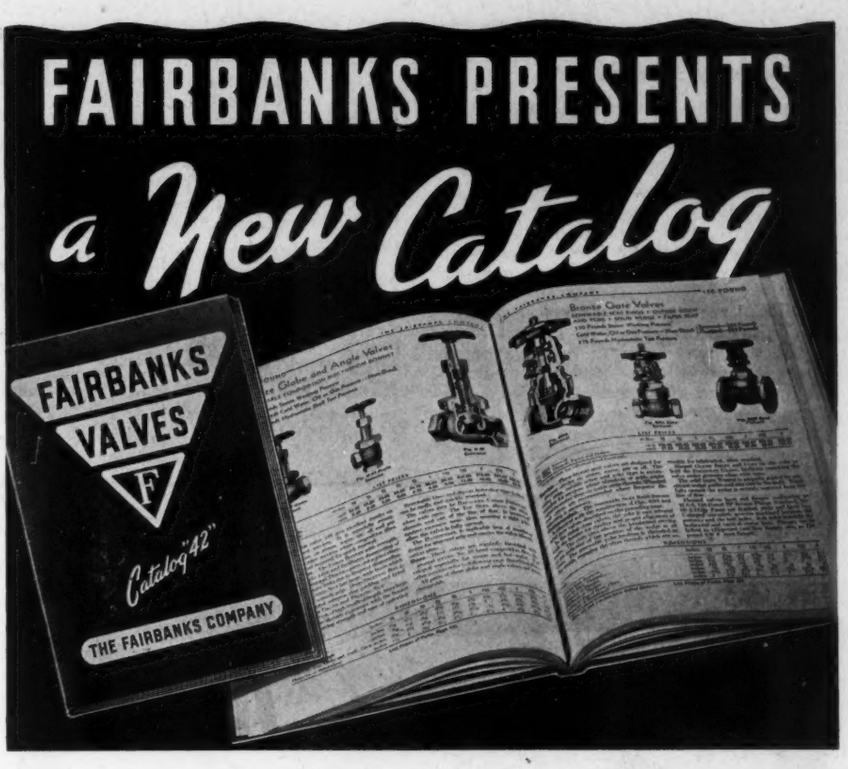
"The Institute learns with the greatest regret that Professor Stanislaw Pilat died at enemy hands in Lvow recently. He was sacrificed at the altar of Polish science and culture by a ruthless foe.

"It is grevious to all right-minded people that the dogs of war should so afflict the very men whose whole lives and activities are devoted to the common good and surely a grevious retribution must fall on the assassins who are responsible for the blood of these innocent scientists.

"Professor Pilat was a prolific writer and a survey of his researches shows that he studied with characteristic energy the chemistry of naphthenic acids and their derivatives. Looking ahead, his work on gases and selective solvents will clearly give him a place in the hierarchy of petroleum chemists. He was always interested in the synthesis of compounds that simulated or even excelled the properties of natural hydrocarbons.

"Our thoughts go out to his widow, Madame Newman-Pilat.

"In Professor Pilat German barbarity has robbed us of an outstanding personality in the world of petroleum technology and one who was a loyal and generous friend of those who could claim to be his intimates.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## War Topics Stressed At Safety Sessions

Squeezed into a three-day period, October 27, 28 and 29, Petroleum Section meetings at the National Safety Congress in Chicago were marked by a vigorous sense of wartime responsibility on the part of speakers and delegates alike. With few exceptions, addresses and discussions were directed at problems of special importance to the war effort.

Official recognition of petroleum safety engineers' activities as a vital factor in the war was brought out by the annual report of the section's General Chairman for the past year, F. R. McLean, Socony-Vacuum Oil Company, Detroit. Shortly after Pearl Harbor, the executive committee had drafted a War Program which, with the offer of the Petroleum Section's Services, was offered to the Petroleum Industry War Council. Subsequently, a number of general meetings and informal discussions were held and just recently the PIWC's committee on Protection of Plant Facilities was reorganized to provide greater representation of Petroleum Section members.

Among speakers from outside the Petroleum Section ranks were Major Frank E. Wilder, Office of Provost Marshall General, Washington, D. C., and B. L. Majewski, vice president of Deep Rock Oil Corporation, Chicago, Illinois, and chairman of the National Marketing Committee of the PIWC. Major Wilder, by his choice of a subject, called attention to anti-sabotage as a new phase of safety engineers' activities in the petroleum industry. Mr. Majewski pointed to the greatly increased interest of top management on safety engineering within the past year and the success attending the oil industry's war efforts to date. There is no record, he said, of a military operation failing because of a lack of petroleum supplies at the front.

About 150 petroleum safety engineers attended a luncheon at the Medinah Club at which Alvah H. Small, president of Underiwriters Laboratories, explained the functions of that organization. Later, the Petroleum Section delegates, joined by representatives of the Ordnance Department were escorted through the laboratories and provided a demonstration and explanation by Underwriters' engineers. The tests demonstrated were those of particular importance to petroleum industry.

Exchange of information on petroleum safety by delegates was supplemented by formation of a new committee to develop means of reducing off-duty accidents among oil industry employes. The committee is believed to be the first of its kind formed by an industrial section of the National Safety Council. It is a direct outgrowth of the war, any accident that keeps a man away from his work being recognized as a serious detriment to the war effort. Roy Bonsib of Socony-Vacuum Oil Company, New York, was appointed chairman.

At the election of officers October 28, H. T. Markee, Phillips Petroleum Company, was named general chairman of the Petroleum Section. He succeeds F. R. McLean, Detroit, Socony-Vacuum Oil Company.

Other officers elected were: J. L. Manes, Dallas, Sun Oil Company, vice chairman for production; J. J. Reilly, Boston, Tide Water Associated Oil Company, vice chairman for Marketing; J. C. Askam, Findlay, Ohio Oil Company, vice chairman for pipelines; W. W. Weldon, Baton Rouge, Standard Oil Company of Louisiana, engineering vice chairman; W. A. Allred, Dallas, Lone Star Gas Company, news letter editor.

Others elected were: Q. R. Dungan, Bartlesville, Oklahoma, Cities Service, chairman of engineering committee; Dr. V. M. Brian, Lawrenceville, Illinois, Indian Refining Company, chairman of health committee; J. L. Risinger, New York, Socony-Vacuum Oil Company, chairman of industrial data sheet committee; John C. Ebel, New York, Shell Oil Company, Inc., chairman of publicity committee; F. M. Russell, San Francisco, Standard Oil Company of California, chairman of visual education committee.

Roy S. Bonsib, New York, Socony-Vacuum, was also named chairman of the Atlantic division of the council, besides being chairman of committee on "off-the-job-safety."

Other officers elected were: R. T. Henderson, Cleveland, Ohio Standard, chairman of Great Lakes division; Lee B. Conner, Houston, Texas Company, chairman of Gulf Coast division; D. A. Klemme, Tulsa, Stanolind Oil & Gas Company, chairman of Mid-Continent division; Carl J. Meiser, Boston, Sun Oil, chairman of New England division; W. E. Lovejoy, Taft, California, Standard of California, chairman of Pacific Coast division, and D. V. Stroop,

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New York, secretary of the Petroleum Section.

H. N. Blakeslee resigned as secretary, due to the press of other business, after sixteen years' service in that capacity. In apprciation of his contributions to the Petroleum Section's progress, members presented him with a portable radio.

### Would Hold Technical Men Out of Military

Dr. Gustav Egloff, president of the American Institute of Chemists, has urged retention of technically trained men and women in present activities in a telegram to Senator Robert A. Taft. Copies were sent to all members of the United States Senate. His summary of the situation was summed up in the following message:

"Heartily agree with your proposed amendment to manpower bill to insure adequate supply of scientifically and technically trained men and women. Suggest three steps in this direction: first, do not draft scientists and technologists, retain chemists, chemical engineers and other scientifically trained persons in present wartime production jobs; second, continue to graduation education of scientific and technical students, both men and women; third, encourage more women to study sciences to fit them for technical wartime jobs.

"I estimate 75,000 to 100,000 graduate chemists and chemical engineers in United States. War plants already operating, under construction or planned to produce war materials, such as aviation gasoline, rubber and explosives, and many other war efforts, will require at least double this number, not to mention other services contributing to the war effort, such as technical branches of Army and Navy.

"As director of Research, Universal Oil Products Company, I am personally concerned at developing serious shortage of technically trained men and women."

### Canadian Requirements On Domestic Basis

Requirements for materials for refining in Canada have been put on the same basis as those of the United States by Harold L. Ickes, Petroleum Coordinator for War.

As a result of the closer cooperation between the Oil Controller of Canada and the Office of Petroleum Coordinator for War, all Canadian applications for materials and for petroleum products will be processed, considered, and appraised just as similar requirements for the United States are processed.

At the same time, provisions have been made for Canadian materials requirments to be transmitted to the OPC by the Canadian Oil Controller for program determination, just as though they were United States requirements.

Detals of the plan were included in a letter addressed to Dominion Oil Controller G. R. Cottrelle by Deputy Coordinator Ralph K. Davies.

The Deputy Coordinator wrote:

"On the basis of (conferences) and in the spirit of the Hyde Park agreement and the Canada Proclamation, I now wish to advise you that as respects all forms of consideration given all Canadian petroleum matters by this Office, Canada will henceforth rank on precise parity with the United States.

"As soon as the indicated arrangements can be made fully effective, the


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# *Design and Material Equally Important* in Coke "Breeze" Pumps

"Water-ends" of Amsco-Nagle centrifugal pumps are always made of metals best suited to withstand the corrosive or abrasive conditions under which each specific pump must operate. Three pumps recently made for a petroleum refinery were fitted with water-end parts of manganese steel.

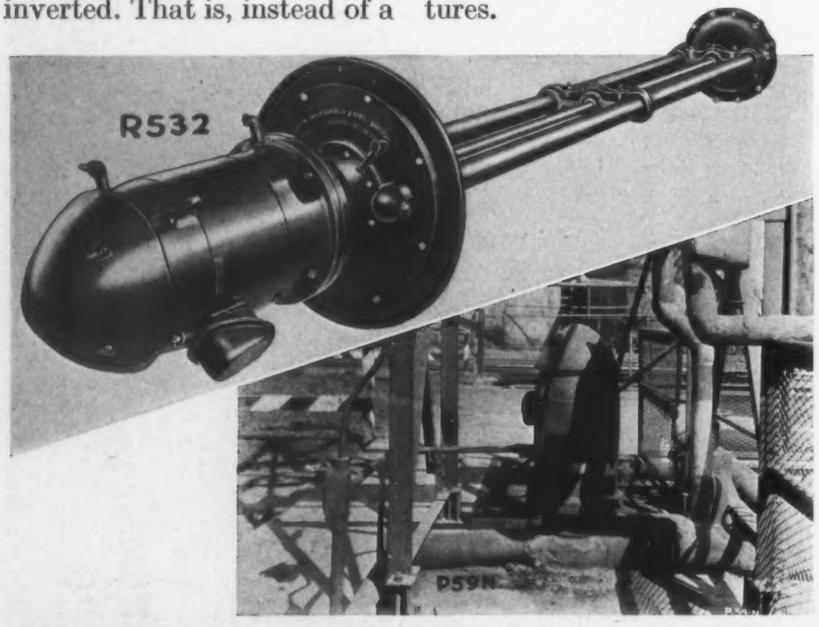
These pumps, one of which is pictured before and after installation, are Amsco-Nagle 3″ type "SW" units with 14″ impellers. They handle, in a coking unit quenching system, water containing petroleum coke "breeze" which, being excessively abrasive, has a severe scouring action that is satisfactorily resisted by the 13% manganese steel.

The design plays an equally important part in the successful operation of these pumps, which have been on the job over a year and a half. Notably, the water-end inlet is inverted. That is, instead of a side or bottom inlet, the liquid enters from the top of the casing. This eliminates air or gas binding. Simple, liberal slippage seal adjustment is provided.

In addition, intermediate and steadying sleeve bearings, in split yoke retainers, are lubricated from above the floor plate. The tubular structural members serve a dual purpose, one as an outlet pipe and the other as a duct for lubricant to the submerged bearings.

This is only one of many cases where Amsco-Nagle Pumps are economically serving the process industries. Amsco-Nagle Pumps are available in horizontal and vertical shaft types, from ¾″ to 12″ pipe, with impellers up to 28½″ diameter and for capacities as great as 8,000 g.p.m. and heads as high as 200 ft.

Bulletin 940 thoroughly covers the many design features.

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revised procedure for Canadian petroleum will assure the following important objectives:

"1. A closer community of interest between Canada and the United States on all subjects relating to petroleum.

"2. The inclusion of Canadian requirements for petroleum and petroleum materials with those of the United States for applications to, and allocations by, the War Production Board.

"3. The consideration of Canadian petroleum war plants as integral units of the United States war plant construction program and the scheduling of material deliveries in harmony with that program."

## Rationing Postponed For the Nation

Delays in the transportation of forms and books necessitated issuance by the Office of Price Administration November 10 of an order postponing the inauguration of nationwide gasoline rationing from November 22 to December 2.

The OPA explained that the wartime transportation system had proved unable to move the more than one-third billion pieces of printed matter necessary for the rationing, on scheduled time and a number of local boards would not secure their supplies in time to permit registration of motorists on November 12-14, as planned. In districts where forms have not been received, boards were authorized to postpone registrations to November 18-20.

From the standpoint of motorists outside the currently rationed area the postponement was a double windfall, since it gave them 10 days more of unrestricted driving and would give them something over four gallons of gas more during the initial ration period than they would otherwise have secured, the latter as a result of a decision by the OPA not to tear coupons out of ration books to cover the ten-day period.

## Change Asked For Wage-Hour Law

Through a resolution of the Gulf Coast Refiners Association has gone on record in favor of extending the working week to hours longer than 40. The resolution follows:

"The existing manpower shortage can be reduced and efficiency and production improved by permitting a work week of at least 48 hours, or possibly 56 hours and it is recommended that legislation be immediately passed by the national Congress authorizing labor and industry to adopt a work-week of such larger number of hours. The association favors, therefore, a work week of at least 8 hours per day for at least 6 days per week in order to more fully take advantage of all available manpower.

"The association further believes that as long as price ceilings are imposed on the oil industry, the penalty of extra pay should not be imposed for a work week of no more than 48 to 56 hours. The growing shortage of manpower and the necessity for curbing inflationary trends both point to the necessity for immediate modification of existing wage-hour legislation. Refining operations under existing price ceilings and under current governmental directives render it impossible for the refiner to absorb increases in costs of operations."

# Serious East Coast Shortage Foreseen by War Council

DAILY shortage of 100,000 barrels of petroleum products for the Atlantic Seaboard area over the next five months is anticipated by the Economics Committee of the Petroleum Industry War Council. So serious is the outlook, prompt reduction of Eastern gasoline allowances was suggested, along with other recommendations. This prospect was outlined by Dr. Robert E. Wilson, committee chairman, at the council meeting in Chicago last week.

The council, at the same meeting, adopted a strongly worded resolution opposing subsidies from government agencies to encourage oil field development. Reasons set forth were that no such plan could accomplish the desired objective, that administrative problems would be unsurmountable, that it would encourage unsound projects, and that it would jeopardize the American system of free enterprise. The same resolution called for a fair and adequate price for crude oil as a better means of providing for reserves.

Another resolution adopted by council members asked for a speed for trucks in excess of the 35 mile an hour limit fixed by the Office of Defense Transportation. It stated this was necessary to provide essential hauling capacity for the nation.

Failure of tank car deliveries to reach the total hoped for in some circles as well as consumption of gasoline at rates higher than anticipated were given as reasons for the East Coast shortage. The report brought out the possibility that increased military activity may further influence shortages in the area. No relief is in prospect, it said, until the 24-inch pipe line is completed.

The report also emphasized the refining problems created by cutting passenger car gasoline consumption to 50 percent of normal and overall gasoline consumption to 75 percent of normal, while heavy demands for fuel oil still persist. The drastic readjustments in refinery yields required to bring this about necessitate the prompt adoption of some plan for compensating refiners for producing less of their high-priced products and more of their lower-priced products, the report asserted.

A summary view of the Eastern Seaboard outlook as compiled by the economic committee is presented in an accompanying tabulation. The deficits indicated of approximately 50,000 barrels daily, or some 7 million barrels over the winter period, were calculated on the basis of supplying only rationed demands as measured by existing rationing orders. On the assumption that the rationed requirements of fuel oil must be supplied, the shortage, if applied solely against gasoline, would require such a reduction in gasoline stocks as to be obviously unattainable. Thus the shortage must be made up by either (a) a further reduction in the gasoline ration, or (b) the provision of additional tanker transportation. As additional tankers appear unlikely, the shortage indicated would be increased to over 100,000 barrels daily if tank car movements cannot

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**Summarized Table Showing Forecast of Supply and Demand for District 1**
**(1000s of Barrels Daily)**

| | November | December | First Quarter | Second Quarter | Third Quarter | Fourth Quarter | Year |
|---|---|---|---|---|---|---|---|
| SUPPLY | | | | | | | |
| From Outside | | | | | | | |
| Tank Car | 811 | 840 | 867 | 960 | 860 | 810 | 871 |
| Pipe Line | 155 | 159 | 191 | 197 | 457 | 490 | 334 |
| Barge and Lake Tanker | 108 | 110 | 114 | 180 | 195 | 159 | 162 |
| Deep Sea Tanker | 100 | 100 | 75 | 25 | 25 | 25 | 37 |
| Local Production | 85 | 85 | 85 | 85 | 85 | 85 | 85 |
| Total Supply | 1,259 | 1,294 | 1,332 | 1,447 | 1,612 | 1,569 | 1,489 |
| DISTRICT I DEMAND (Local and Export) | | | | | | | |
| Gasoline* | 467 | 465 | 465 | 484 | 489 | 491 | 482 |
| Kerosene* | 140 | 178 | 147 | 75 | 73 | 145 | 110 |
| Distillates* | 273 | 337 | 312 | 133 | 107 | 245 | 200 |
| Fuel Oil* | 340 | 372 | 373 | 313 | 294 | 337 | 329 |
| Other | 130 | 130 | 126 | 139 | 143 | 143 | 138 |
| To Other Districts | 20 | 19 | 19 | 19 | 19 | 19 | 19 |
| Total Demand | 1,370 | 1,501 | 1,442 | 1,163 | 1,125 | 1,380 | 1,278 |
| Change in Stocks | —111 | —207 | —110 | +60 | +92 | +26 | +16 |
| Average Daily Shortage versus desirable minimum stock levels of 52,000,000 barrels as of March 31, 1943 | 50,000 | 50,000 | 50,000 | None | None | None | |
| Surplus for additional export versus minimum desired stock levels | None | None | None | 224 | 395 | 163 | 195 |

* Local demand rationed.

be raised over recent delivery of around 750,000 barrels daily. Significantly, shipments by tank car, which gradually increased from 100,000 barrels per day in January to 830,000 barrels daily in September, with practically no interruption in their continuous rise, of late have had an erratic and somewhat downward trend. This would indicate it is unsafe to count upon daily deliveries materially in excess of 800,000 barrels, or thereabouts, over the cold months.

Furthermore, the excess rates at which tank cars have been operated during the past few months makes it logical to anticipate more cars out of service for repairs.

The estimated deficiencies and overages of supplies shown, the economic committee warned, are subject to modification to the extent that unforeseen military demands, either on supplies or transportation, may have to be met. Naturally, larger consumption by military forces are anticipated.

Besides the East Coast shortage, another serious problem facing the oil industry is the necessity of making major readjustments in refinery product yields. Imposition of nationwide rationing of gasoline on November 22 brings to a sharp focus the impending radical decline in total motor gasoline consumption. The reduction expected is calculated to be of the order of 13 percent as compared with recent demand, which already has reflected the effect of voluntary conservation, and this reduction will be super-imposed upon a situation in which demands for other products are pressing upward. This situation, obviously, calls for a pattern of refinery output entirely different from that heretofore prevailing. The only possible way, the report declared, in which to meet this situation is through adjustment of refinery yields so that each refinery area will be turning out substantially less gasoline and materially more fuel oil.

Adjustments in yields are considered necessary to achieve a balance between supply and demand. If yields indicated for the future period are not attained, the committee predicted an overproduction of gasoline and an underproduction of fuel oils; and, as the gasoline accumulates in storage, the necessity for reducing runs would be aggravated, and the shortage of fuel oils would be accentuated. Finally, and as a consequence of lack of earlier action, the yields would have to be adjusted even more radically than at present. To avoid this uneconomic chain of developments, the committee urged immediate adjustment of refinery yields.

If the current yields were continued through the coming winter, gasoline would be overproduced in District 1, 2, 3, and 4 by 106,000 barrels daily, with a shortage in residual fuel oil production of 88,000 barrels daily. The fuel oil shortage could be met in part by the conversion of the indicated surplus of distillate to heavy fuel oil. Limitations in available gasoline storage would further aggravate this underproduction of fuel oil.

The entire situation is complicated by the necessity of maintaining full production of war products, which requires certain levels of crude runs and gasoline production. Due to the necessity of preserving gasoline outlet for war product plants, a large proportion of the crude available for running in non-war product plants will have to be processed in a simple topping operation. This lack of balance will increase as more refinery facilities are installed for the manufacture of war products.

The committee offered the following suggestions and recommendations to meet the situation:

(A) Every effort should be made to

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To "guess" at the temperature would be fatal. Give your workmen an easy-reading thermometer and eliminate any guess-work and thus save spoilage.

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With scientific annealing and careful testing, PALMER builds a thermometer that you can depend upon and then we give you a bright RED column to make the work easier. A full dollar value for every dollar paid.

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speed up completion of all transportation projects relating to the delivery of oil to the Eastern Seaboard.

(B) Feeder lines which are to supply heating oil to the big-inch line from the Corpus Christi, Houston and Beaumont-Port Arthur refining should be in full operation by the time the line is ready to receive supplies. The big line should be filled with heating oil because this will accomplish delivery of a needed product during the most critical (winter) time, ample stocks of distillate oil are available in District 3, and this will add to flexibility in operation of refineries producing essential war products.

**Table Showing Changes in Percentage Gasoline Yields by Refinery Districts Necessary to Create a Balanced Situation After Gasoline Rationing Is Imposed**

| | 1941 Actual | 4 Weeks Ended Oct. 24 Act. 1 | Nov.-Mar. 1942-43 Estimated | Remainder 1943 Estimated |
|---|---|---|---|---|
| DISTRICT I.. | 39.4 | 37.9 | 37.7 | 38.2 |
| DISTRICT II.. | 52.2 | 45.2 | 39.8 | 42.7 |
| DISTRICT III.. | 44.4 | 38.7 | 35.5 | 39.0 |
| DISTRICT IV.. | 50.6 | 40.7 | 44.2 | 43.9 |

(C) Further effort should be made toward increasing tank car movements to the Eastern Seaboard by expediting of trainload lots, by pooling of facilities, by other steps.

(D) Prompt consideration should be given to a reduction of gasoline rationing allowances in the Atlantic area.

(E) Upon the exhaustion of the first three recommendations listed above, the only alternative remaining is allocation of additional tankers for deliveries to the East Coast.

(A) The necessity of altering refinery yields in advance of the development of serious unbalances is so great that increased and prompt attention should be given to the development of a program. The committee recommended OPC give attention to this matter.

(B) Further study also is needed on the relationship of the production of aviation gasoline, toluene, butadiene, and other war materials to the levels of crude runs and refinery yields and the effect on non-war product refineries.

The committee also made some general recommendations, including further conversion of distillate and residual fuel oils users to coal in District 1 area.

## *Refining Engineers Win In Lincoln Contest*

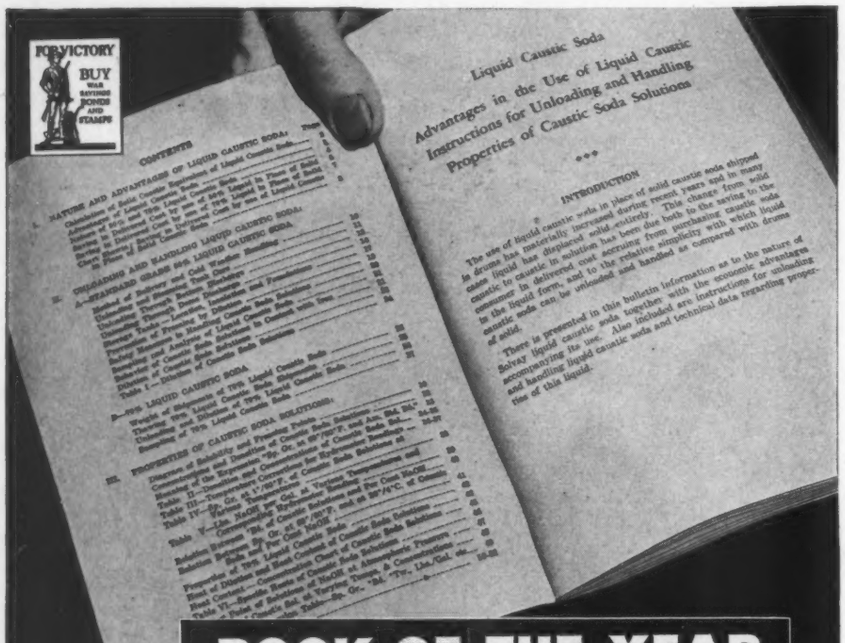
Among the winners in the $200,000 award of the James F. Lincoln Welding Foundation were W. W. McClow, assistant general maintenance foreman at the Toledo plant of The Pure Oil Company, and Egon F. Brummerstedt, mechanical engineer in the petroleum division of Foster Wheeler Corporation, New York.

McClow dealt with the application of stainless-steel lining to fractionating towers. In December, 1940, he gave the practical application of this procedure in an article, "Layout and Application of Stainless Steel Strip to Refinery Vessels," in PETROLEUM REFINER.

His award from the contest was $3,700.

An award of $700 went to Brummerstedt, whose subject matter was in the use of arc welding in the design and construction of a vacuum fractionating

W. W. McCLOW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tower, 35 feet wide, one of the largest units ever constructed for a refining plant.

Other winners in the refining field were Everette E. Kerns, mechanical engineer, Standard Oil Company of Ohio, Cleveland; Harold F. Stedman, assistant maintenance foreman, The Pure Oil Company, Toledo.

The $200,000 awarded through the foundation went to 458 recipients, in 408 awards. Joint authorships accounts for the discrepancy. The foundation was established in 1936 in honor of James F. Lincoln, president of Lincoln Electric Company. Benefits of welding as revealed through the practices and economies of the papers prompted this estimate from the foundation:

"Results of the study show the war industries have only begun to gain benefits of modern arc welding; that further application of the welding process will slash hundreds of millions of dollars off the United Nations' war bill and will cut by 30 percent the time required to produce ships and plants.

"Arc welding will turn out vitally needed naval and military equipment which is more combat-proof and at the same time will save an average of 300 pounds out of every ton of steel going into war production."

## Catalog of Technical Books Is Available

The new catalog of technical books of the Chemical Publishing Company, 234 King Street, Brooklyn, is now available.

For the 1942-43 edition the format was especially designed to enhance its utility and efficiency. Sections have been subdivided so needed books or books on similar subjection may be found in a minimum of time.

Every important field has been covered, aviation, engineering, electricity, radio, mechanics, chemistry, formulas and military and naval sciences are a few of the divisions. Included are the Spanish and Portuguese books of Editorial Tecnica Unida, the Spanish subsidiary of Chemical Publishing Company, Inc.

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# DIGEST OF UNITED STATES PATENTS

## Newer Patents on Catalytic Alkylation of Hydrocarbons

Compiled by
HEINZ HEINEMANN, Attapulgus Clay Company

**U.S.P. 2,223,938. Alkylation of Hydrocarbons.** E. F. Pevere, L. A. Clarke and G. B. Hatch to The Texas Company.

Hydrocarbons are alkylated in the presence of a catalyst. In particular the process refers to the alkylation of i-butane with low-boiling olefins ($C_3 - C_4$) in the presence of 88 to 100 percent sulfuric acid (preferably 94 percent) or of other liquid catalysts like with $BF_3$ saturated water. The olefinic feedstock is at first treated with partially spent catalyst and freshly made up catalyst is introduced to the reaction zone at a point substantially beyond that at which the olefinic hydrocarbons are admitted. Catalyst is withdrawn from an intermediate stage and is recycled. The ratio of iso-paraffin to olefin is 3:1. The amount of fresh acid added corresponds to ¼ to 5 times the volume of olefins. The preferred reaction temperature is 60 to 90° F.

**U.S.P. 2,224,102. Reaction of Hydrocarbons.** M. M. Holm, E. H. Oakley and R. L. Humphreys to Standard Oil Company of California.

Isoparaffinic hydrocarbons are alkylated with olefins in the presence of sulfuric acid as a catalyst. The operation takes place preferably in the liquid phase at a temperature of from 15 to 150° with an acid concentration of 95 to 98 percent prevailing. It is an essential part of this invention to keep the concentration of alkyl acid sulfate in the sulfuric acid below about 1 percent by weight of the acid.

**U.S.P. 2,225,544. Manufacture of Alkylated Isoparaffinic Hydrocarbons.** A. L. Blount to Union Oil Company of California.

Isoparaffins and olefins can be alkylated in the presence of $H_2SO_4$. Increasing concentration of $H_2SO_4$ increases the yields of desirable branched-chain hydrocarbons boiling within the gasoline range. However, sulfuric acid of higher strength when brought into contact with the described hydrocarbons tends to react so as to produce certain undesirable side reactions with the incidental formation of $SO_2$, carbonization products and water. The water dilutes the $H_2SO_4$ catalyst and forms acid-mono-hydrates lowering the activity of the catalyst. Dehydrating agents other than the catalyst are therefore added, greatly increasing catalyst life. Pyro sulfates and pyro phosphates are suitable agents.

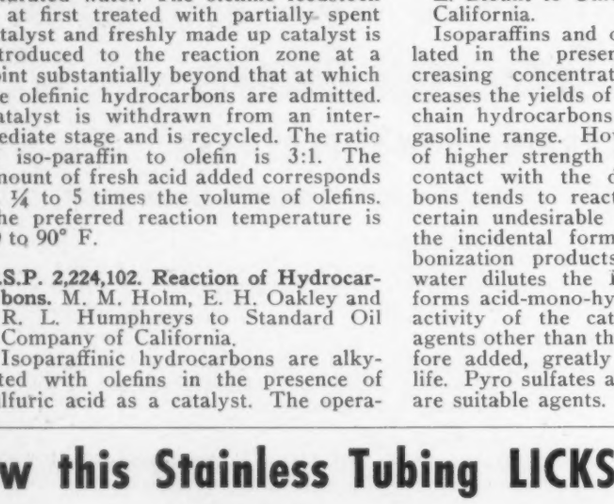
**U.S.P. 2,234,984. Alkylation Process.** A. N. Sachanen & S. B. Davis to Socony-Vacuum Oil Company.

Alkyl aromatic compounds and in particular alkyl benzenes are prepared by treating a mixture of aromatic and paraffinic hydrocarbons at a temperature upwards of 850° with a catalyst comprising an association of silicon oxide and aluminum oxide, or with a clay catalyst.

**U.S.P. 2,236,099. Treatment of Paraffin Hydrocarbons.** V. N. Ipatieff and H. Pines to Universal Oil Products Company.

Iso paraffins are alkylated with olefins under properly chosen conditions of temperature, pressure, concentration of reactants and time of contact so that the normally vigorous polymerization action of the catalysts employed is moderated so that alkylation occurs rather than polymerization. Metalhalides together with small amounts of HCl are used as catalysts at proper temperatures. For aluminum chloride, the most effective catalyst, a temperature of —50 to +60° may be used while zinc chloride and ferric chloride will require 100 to 200°C.


# How this Stainless Tubing LICKS TOUGH CORROSION PROBLEMS



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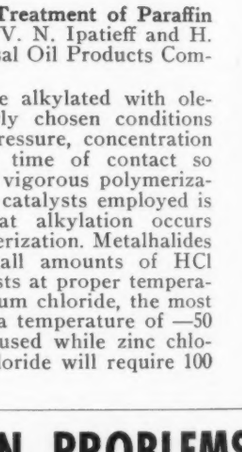

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**U.S.P. 2,238,594. Catalytic Treatment of Hydrocarbons.** Boris Malishev to Standard Oil Development Company.

Aromatic hydrocarbons are alkylated with olefins in the presence of phosphorus pentoxide as a catalyst and carbon black as a protective colloid under addition of hydrogen, gaseous hydrides or compounds capable of liberating these under reaction conditions. Such hydrides are $H_2S$, HCl, HBr, HI, HF, HCN. A temperature of 250 to 400° is used at elevated pressure.

**U.S.P. 2,238,860. Manufacturer of Motor Oil.** L. C. Kemp to The Texas Company.

A process for the conversion of natural gasoline to high-octane motor fuel is claimed which includes the step of alkylating iso-butane obtained from n-butane by isomerization with olefins from the cracking of heavier products, using catalysts like $H_2SO_4$ or a liquid saturated with $BF_3$.

**U.S.P. 2,240,134. Treatment of Hydrocarbon Oils.** Gustav Egloff to Universal Oil Products Company.

The catalytic treatment of gas oils is described. They are treated at 500 to 700° F. and elevated pressure with a catalyst consisting essentially of $FeCl_3$ and $AlCl_3$ and with a minor amount of HCl present to produce substantial amounts of normal and iso-butane. The n-butane is thermally cracked to olefins which are alkylated with iso-butane at a temperature of 10 to 30° C. when using 90 to 100 percent $H_2SO_4$, or 200 to 400° and 2000 to 5000 pounds when using a granular $H_3PO_4$ catalyst. Alkylation of iso-butane and ethylene can be obtained thermally at 900 to 1000° and 1000 to 5000 pounds, producing neohexane.

**U.S.P. 2,242,845. Alkylation.** A. L. Blount to Union Oil Company of California.

Equations are given to determine the reaction temperature or the reaction temperature range of an alkylation process using a concentrated sulfuric acid catalyst. $Y=0.25X+47$, where Y is the temperature to be employed in °F and X is the propylene content (of a propylene-butylene mixture) expressed as percent by volume of the $C_3 + C_4$ in the olefin mixture.

**U.S.P. 2,242,960. Production of Motor Fuel.** A. N. Sachanen and A. O. O'Kelly to Socony-Vacuum Oil Company.

Aromatic hydrocarbons are alkylated with olefinic hydrocarbons in either batch or continuous operation at a temperature of from 400 to 600° and 50 to 250 pounds pressure in the presence of a clay catalyst, obtaining from 57 to 100 percent of the theoretical yield, the majority of which boils within the gasoline range.

**U.S.P. 2,245,038. Hydrocarbon Reaction.** M. M. Holm and E. H. Oakley to Standard Oil Company of California.

Isoparaffin and olefin are alkylated in a continuous process with a sulfuric acid catalyst in such a manner that two zones of reaction are maintained, the first of which is of smaller capacity than the second and contains a means of mechanical agitations for intimately contacting two immiscible liquids. Olefins, an excess of iso-paraffin and sulfuric acid are charged under alkylation conditions into the mixing device, the resulting mixture is introduced into the secondary zone of reaction in which at least a partial separation of acid and hydrocarbons is effected. Thus a higher volume ratio of acid to hydrocarbon is maintained in the first than in the second zone. Constant replacement of sulfuric acid keeps up its concentration. The acid consumption is greatly reduced in this process.

**U.S.P. 2,246,703. Alkylation.** E. W. Thiele and R. C. Gunnes to Standard Oil Company (Indiana).

Iso-paraffinic hydrocarbons of the $C_4$ to $C_6$ group are catalytically alkylated with normally gaseous olefins in the presence of concentrated sulfuric acid in a process which comprises concurrently flowing a mixture of the liquefied components through a long, closed reaction zone, providing high-speed mixing in the reaction zone to obtain a fine dispersion of hydrocarbons in acid throughout the length of the reaction zone, regulating the pressure so as to keep the hydrocarbon boiling range at from 40 to 100° F., removing and condensing the hydrocarbon vapors evolved in the reaction zone and recycling them.

**U.S.P. 2,256,880. Alkylation of Hydrocarbons.** A. R. Goldsby and J. C. Van Gundy to Texaco Development Corporation.

A multi-step alkylation process using a liquid catalyst is described. The charge consisting of n- and i-butane and olefins is given to a series of reaction stages where alkylation takes place. A reaction mixture is continuously with-


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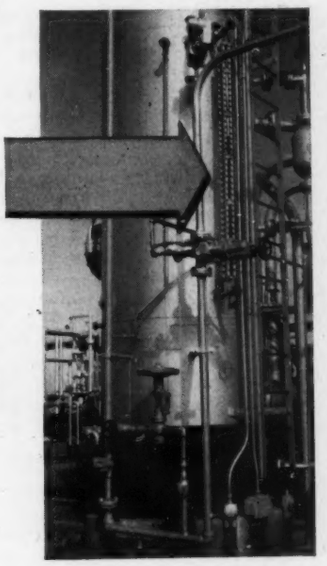

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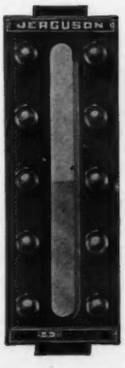


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drawn from each stage, separated into a normally gaseous phase (rich in iso-butane) which is mixed with fresh olefin and recycled, a normally liquid hydrocarbon phase from which part is discharged and part given to the next reaction stage and a catalyst phase which is returned to the phase from which it was withdrawn.

**U.S.P. 2,257,920. Treatment of Petroleum Products.** A. N. Sachanen and R. C. Hausford to Socony-Vacuum Oil Company.

Alkyl aromatic hydrocarbons entirely of petroleum origin and boiling above 300° C. are normally found in petroleum tars. To convert them into alkyl aromatic hydrocarbons boiling below about 300° C. they are treated with benzene in the presence of a metal halide catalyst at a temperature of between 80 and 200° C.

**U.S.P. 2,258,236. Treatment of Hydrocarbons.** W. L. Benedict and L. C. Kassel to Universal Oil Products Company.

A mixture of a major proportion of an iso-paraffinic hydrocarbon and a relatively smaller proportion of an olefinic hydrocarbon are charged to a primary alkylation treatment in the presence of both an aluminum halide catalyst and a hydrogen halide. The reaction products are separated from the catalyst and subjected to a secondary alkylation treatment in the presence of sulfuric acid to form a substantially saturated alkylate. Unreacted hydrogen halide and iso-paraffin are recycled as well as a portion of the partially spent sulfuric acid.

**U.S.P. 2,267,097. Alkylation of Hydrocarbons.** G. B. Hatch, E. F. Pevere, L. A. Clarke and F. H. Brumer to The Texas Company.

Iso-paraffins and olefins are alkylated in the presence of a liquid catalyst. Feed hydrocarbons and catalyst are continuously introduced to a vertical reaction vessel. A stream of mixed catalyst and hydrocarbons (including alkylate) is withdrawn continuously from the upper portion of the vessel. A substantial portion of the withdrawn stream is recycled to the lower part of the vessel so as to impart agitation to the fluid contents of the vessel. The non-diverted portion of the withdrawn mixture is separated and the catalyst partially recycled.

**U.S.P. 2,267,730. Alkylation of Paraffin Hydrocarbons.** A. V. Grosse and C. B. Linn to Universal Oil Products Company.

Iso-paraffins and olefins are alkylated by a HF catalyst. The HF should be highly concentrated and preferably anhydrous. Best results are obtained at room temperature. A paraffin-olefin ratio of 3:1 is advantageous.

**U.S.P. 2,269,302. Manufacture of Gasoline.** H. V. Atwell and F. H. Brumer to The Texas Company.

Propylene is absorbed in concentrated sulfuric acid of alkylation strength and the mixture is treated with iso-butane and a butene in the liquid phase under alkylation conditions effective for the alkylation of the butene by the iso-butane. Under these conditions the absorbed propylene is also alkylated by the iso-butane, forming saturated hydrocarbons of high octane number within the gasoline boiling range.

**U.S.P. 2,271,860. Treatment of Hydrocarbons.** A. R. Goldsby to The Texas Company.

Low-boiling iso-paraffins, olefins and normal-paraffins are subjected to alkylation conditions. The iso-paraffins and olefins are condensed to higher-boiling iso-paraffins. The normal-paraffins are separated from the reaction product, isomerized and charged to the alkylation reaction to increase the iso-paraffin-olefin ratio.

**U.S.P. 2,273,041. Treatment of Hydrocarbons.** V. N. Ipatieff and H. Pines to Universal Oil Products Company.

An excess of iso-butane and a minor proportion of i-butene, preferably in a 3:1 ratio are subjected to the action of $AlCl_3$ and HCl, whereby the latter should be present in an amount of 1 to 10 percent by weight of the former. An alkylation temperature of above 0° C. is maintained and sufficient superatmospheric pressure (5 to 50 atm) applied to keep a substantial portion of the hydrocarbons in the liquid phase.

**U.S.P. 2,274,858. Alkylation of Iso-Paraffins with Ethylene.** W. E. Bradley to Union Oil Company of California.

Iso-paraffinic hydrocarbons with less than 7 C atoms per mol are contacted under vigorous agitation at 70 to 75° F. and 150 to 200 pounds pressure in the presence of a catalyst consisting of 85 to 100 percent $H_2SO_4$ and a modifying agent comprising about 1 to 10 percent of the total quantity of the catalyst. The modifying agent causes alkylation of iso-paraffins in preference to polymerization of $C_2H_4$ and is selected from the class consisting of the phosphates, sulfates, chlorides, nitrates, acetates and oxides of Cd, Zn, Hg, Cu, Ag and Ba.

**U.S.P. 2,275,377. Process of Manufacturing Motor Fuel.** F. E. Frey to Phillips Petroleum Company.

Paraffinic and olefinic hydrocarbons of from 3 to 6 C atoms are alkylated. A part of the effluent of the alkylation step, comprising hydrocarbons in and below the motor-fuel boiling range are passed over a dehydrogenating catalyst to improve the octane number of the fuel and concomitantly to produce olefins lower boiling than motor fuel, which pass to the alkylation step.

**U.S.P. 2,276,250. Alkylation of Hydrocarbons.** J. C. Morrell to Universal Oil Products Company.

Iso-paraffin and olefin are simultaneously contacted at alkylation temperature with 100 percent sulfuric acid to which has been added an inorganic, oxygen containing boron compound in an amount sufficient to substantially dilute the sulfuric acid and correlating the amount and concentration of the acid, the reaction time and the proportion of olefin to iso-paraffin to effect alkylation of said iso-paraffin by the olefin as the principal reaction with a minimum of olefin polymerization. A temperature of from —10 to +30° C. is proposed.

**U.S.P. 2,278,677. Catalytic Reaction of Olefins.** E. E. Stahly and E. M. Hattox to Standard Oil Development Company.

Normally liquid acyclic hydrocarons boiling in the gasoline range and containing substantial amounts of saturated, branched-chain hydrocarbons are produced from a mixture containing essentially iso-paraffins and mono-olefins with no constituent having more than 16 C atoms to the molecule in the presence of at least one binary compound of uranium under alkylation conditions. Sufficient pressure is applied to keep the reaction in the liquid phase. The uranium compound is deposited on a carrier of clay, activated alumina or acid-treated bentonite. The reaction is carried out in the presence of between 1 and 15 percent of a lower alkyl halide at 15 to 80° F. and 0 to 50 pounds.


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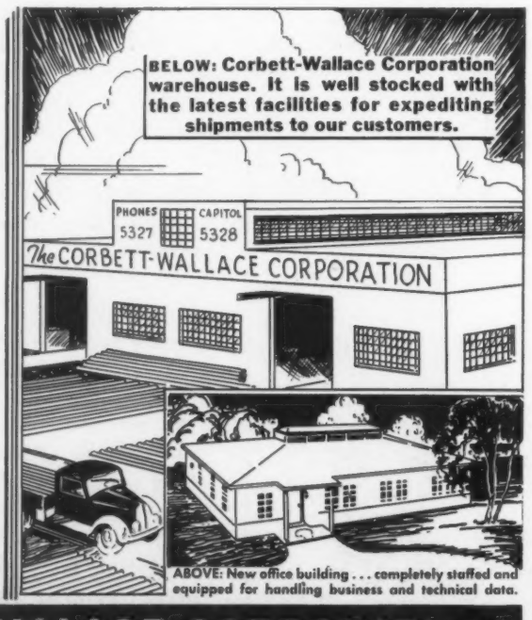
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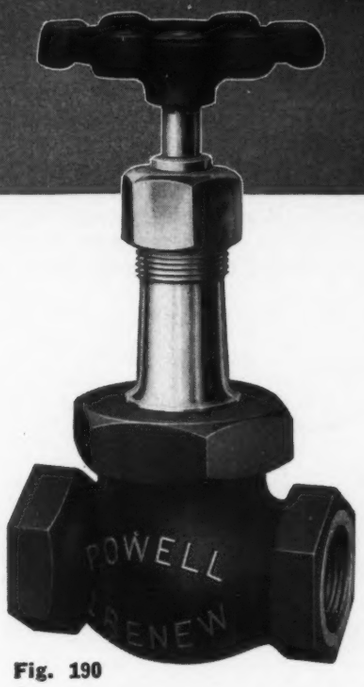


Fig. 190

Fig. 241

## *Switch to POWELL Iron Body Valves wherever possible*

Not so long ago many buyers and users of valves automatically thought of bronze. It was accepted as the standard for many installations . . . apparently the impression existed that the desired service could not be obtained if any other metal were used.

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**Fig. 190**—Iron Body, Bronze Mounted "Irenew" Globe Valve for 150 pounds W. S. P. Has screwed ends, Union bonnet and regrindable, renewable hard bronze seat and disc. Available in sizes from ¼" to 3", inclusive.

**Fig. 241**—Iron Body, Bronze Mounted, Standard "Model Star" O. S. & Y. Globe Valve, with flanged ends, outside screw rising stem, bolted flanged yoke and regrindable, renewable bronze seat and disc. Made in sizes from 2" to 12", inclusive, for 125 pounds W. S. P.

# POWELL VALVES

# SCIENCE AND TECHNOLOGY

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## Fundamental Physical And Chemical Data

**Phase Equilibria in Hydrocarbon Systems,** B. H. SAGE, H. H. REAMER, R. H. OLDS AND W. N. LACEY, *Ind. & Eng. Chem.* **34** (1942) pp. 1108-17.

The specific volume of six mixtures of methane and n-pentane were determined for seven different temperatures between 100° and 460° F. at pressures up to 5000 pounds per square inch. The composition of the dew-point gas was experimentally established throughout the two-phase region for temperatures above 160° F. The specific volume, bubble-point pressure, and dew-point pressure for each of the mixtures, as well as the specific volumes and compositions of the coexisting phases for a number of temperatures, are recorded. The fugacity of each of the components in the coexisting phases was calculated by methods previously described by the authors, and the results of the computations are presented. The data secured in the course of the experimental work are presented in detail in graphical and tabular form.

**The Second Virial Coefficient for Gas Mixtures,** J. A. BEATTIE AND W. H. STOCKMAYER, *J. Chem. Phys.* **10** (1942) pp. 473-6.

The second viral coefficients, B, for methane, butane and 3 mixtures of these gases were determined from experimental data, and the interaction term $B_{12}$ computed for methane-butane from 150° to 300° C. The results were used to study the methods of combination of constants in an equation of state. A method of combination of constants was developed for the equation of state that led to the best results of any method so far used.

**Correlating Vapor Pressure and Latent Heat Data,** D. F. OTHMER, *Ind. & Eng. Chem.* **34** (1942) pp. 1072-78.

A simple relationship has been shown to relate reduced pressures and "reduced latent heats" of any given substance to those of a reference substance, always taken at the same reduced temperature: $\log P_R/\log P'_R = L_R/L'_R$. This equation can be used directly (since there is no constant to evaluate from a plot); and values throughout the entire range of the vapor pressures and latent heats can be calculated or read from a nomogram. It is necessary to know a single point of reduced temperature and vapor pressure, and the values for the reference compound. The equation gives exact plots and eliminates the slight curvatures in the critical regions of the lines of the logarithmic plot for expressing the vapor pressure function. The necessary computations for the interconversion of reduced temperatures and ordinary temperatures and pressures can be made graphically by means of the nomograms presented in the article.

**Binary Mixtures for Testing Fractionating Columns at Atmospheric and Reduced Pressures,** L. B. BRAGG AND A. R. RICHARDS, *Ind. & Eng. Chem.,* **34** (1942) pp. 1088-91.

The vapor liquid equilibria for the system benzene-ethylene dichloride at four pressures. 760 mm., 400 mm., 200 mm., and 100 mm. are presented in tabular and graphical form. Vapor and liquid equilibria are also given for the system o-dichlorobenzene-diethylbenzene at 50 mm. and at 10 mm. Data from the literature are plotted for comparison on the diagrams, and a bibliography showing the sources of these data is included in the article.

## Chemical Compositions And Reactions

**Thermal Behavior of Hexane,** K. BUNTE, H. BRUCKNER AND G. CHOULAT, *Brennstoff-Chem.* **22** (1941) pp. 205-10.

Hexane was heated at 400° C. for 3 hours in the presence of various catalysts such as magnesium oxide, strontium oxide and silver oxide, supported on Raschig rings, and the liquid and gaseous reaction products were analyzed. Dehydrogenation was most marked when using $TiO_2$, and therefore further experiments were made with this catalyst to determine the effects of temperature, catalyst surface, and time of contact. The apparatus used in the work is diagrammatically described. The formation of aromatic hydrocarbons was not found to be effected directly by dehydrogenation and ring closure. It results from the intermediate formation of ethylene, which then loses hydrogen to form benzene. Decomposition of hexane begins at about 400° C., is highest at 685° C., and is complete at 860° C. The formation of aromatic hydrocarbons commences at 685° C. and is highest at 860° C. Up to 860° C. benzene hydrocarbons are the main products, but with further temperature rise the total yield of liquid products decreases and tarry substances and naphthalene are formed. When hexane was passed at a rate of 28 cc./hr. over $TiO_2$, loosely packed, at 860° C. for 35 hours, 35.9 wt.-% of liquid reaction products and 57.8 wt.-% of gaseous products were formed. The liquid products comprised benzene 42%, toluene 5%, xylene 5%, and tar 48%. The gaseous products were composed of methane 46.1%, hydrogen 25.6%, and acetylene 28.3%.

**Catalytic Dimerization of Isobutene by Activated Copper Sulfide,** A. WASSERMANN AND W. T. WELLER, *Nature* **149** (1942) p. 669.

The main product of the catalytic dimerization of isobutene is a mixture of the two 2,2,4-trimethylpentenes. These, on hydrogenation, were converted into 2,2,4-trimethylpentane.

**Oxidation of Hydrocarbons at Low Temperatures,** P. GEORGE, E. K. RIDEAL AND A. ROBERTSON, *Nature* **149** (1942) pp. 601-2.

The oxidation of alkyl benzenes and aliphatic hydrocarbons ($C_{15}$ to $C_{25}$) without a catalyst and with a heavy metal catalyst in the liquid phase at 100 to 120° C. supports the hypothesis that hydroperoxides (reactive group —OOH) are primary oxidation intermediates. For the alkyl benzenes the peroxide found after reaction corresponds to 60-80% of the oxygen absorbed. For the aliphatic hydrocarbons, however, it is approximately only 5%. The catalyzed oxidations appear to show an independence of oxidation rate to catalyst concentration above a certain value. This is explained by the assumption of a chain reaction in which the metal catalyst both starts and stops the chains. The chain character of the reaction is indicated by the fact that it is inhibited by B-naphthol. Copper stearate catalyzes the oxidation of alkyl benzene and tetralin, but not of the paraffins. Cobalt stearate catalyzes all reactions. Copper stearate decreases the rate of cobalt catalyzed oxidation of the paraffins, and

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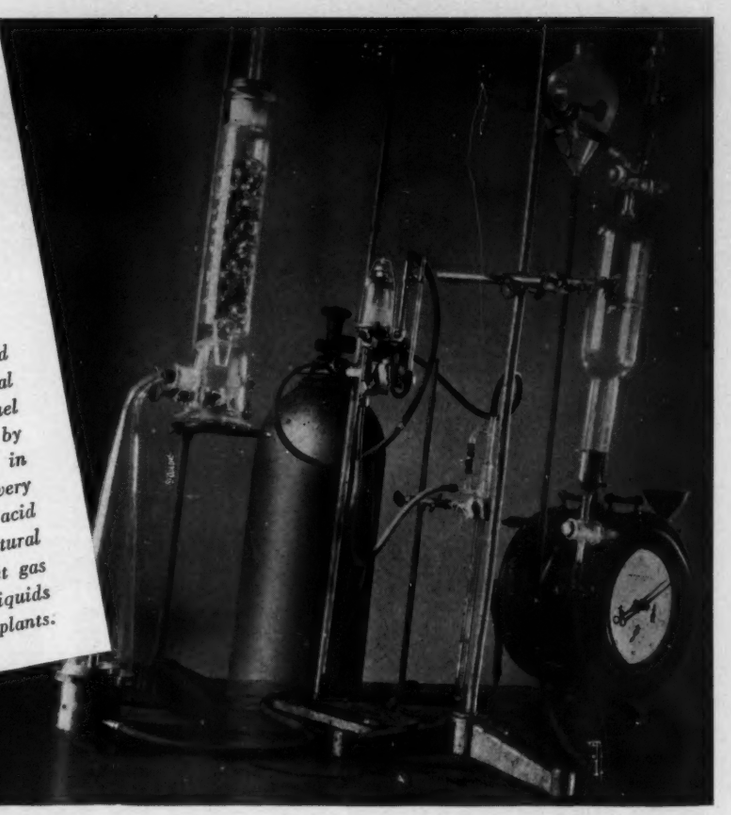

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of uncatalyzed octene mixtures. These results are explained by assuming different chain starting and stopping efficiencies. The hydroperoxides of the paraffins are decomposed almost exclusively to give ketones. The oxidation of mixtures of paraffins with secondary alcohol, ketones or acids, shows that the secondary alcohol inhibits the reaction. The metallic catalyst thus has 3 functions: to start and to stop reaction chains, and to decompose the hydroperoxides formed by the chains.

**Products from the Wurtz Reaction and the Mechanism of their Formation,** A. SAFFER AND T. W. DAVIS, *Jour. Amer. Chem. Soc.* **64** (1942) pp. 2039-43.

On the basis of a free radical mechanism, one would expect a gas phase Wurtz reaction to be complicated, and this is found to be true experimentally. The reaction of methyl iodide or ethyl iodide or a mixture of the two at a pressure of about 200 mm. at 320° C. produces hydrogen, free carbon, saturated and unsaturated hydrocarbons and possibly smaller amounts of higher halides. The character of the products is in harmony with current views concerning free radical reactions. Combinations of two alkyl radicals to give saturated molecules does not seem to occur. Most of the primarily formed free radicals disappear by reaction with excess halide molecules, and the secondary radicals containing iodine disappear either by reacting with each other or by reaction with sodium.

## Manufacture: Processes and Plant

**Mean Temperature Difference in an Array of Identical Exchangers,** K. A. GARDNER, *Ind. & Eng. Chem.* **34** (1942) pp. 1083-87.

Heat exchangers the mean temperature difference characteristics of which have been determined are frequently used in an arrangement which, in itself, constitutes a different type of exchanger. Since the inlet and outlet temperatures for the arrangement are usually the only ones known, a method is required to determine the characteristics of a component exchanger from those of the entire arrangement in order to utilize available information to the fullest extent. A general relationship is given in the article between the mean temperature difference correction factor for an arrangement of identical exchangers and the mean temperature difference correction factor for a component exchanger. A complete solution is given for three common flow arrangements.

**Vaporization Inside Horizontal Tubes,** W. H. MCADAMS, W. K. WOODS AND R. L. BRYAN, *Trans. Am. Soc. Mech. Engrs.* **63** (1941) pp. 545-52.

The changes in the coefficient of heat transfer for the vaporization of a liquid flowing inside a heated horizontal tube were determined. The apparatus used comprised 48 feet of 1-inch copper pipe fitted with 12 individual steam jackets. Runs were made with water and benzene. Inlet velocities were 0.26-1 ft./sec. for benzene and 0.27-0.85 ft./sec. for water. Outlet velocities were 80-240 ft./sec. for benzene, and 205-540 ft./sec. for water. At moderate temperature difference the local overall co-

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| HOW TO FIGHT THEM | Quench and cool this type of blaze with water or extinguishing agents containing large percentages of water. | Blanket this type of fire. Cut off oxygen supply, thus preventing combustion. | Blanketing or smothering is essential. *Use extinguishing agent which is a non-conductor of electricity.* |
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| IN THIS WAY | Aim at base of fire. When fire seems extinguished, look carefully for signs of glowing embers and quench them. | If outdoors, keep wind at your back. If flowing fire, work "upstream." On 2-level fire, work from bottom up. | Shut off electrical current, if possible. Don't stand in puddles or wet places while using extinguisher. |

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efficient at first increases as the fluid is progressively vaporized, but it passes through a maximum, and then decreases sharply toward values typical of superheating dry vapor. This phenomenon, referred to as "vapor binding" is caused by insufficient liquid to wet the wall; small droplets of liquid are carried in the vapor in the center of the tube. When the temperature differences were large the type of vapor binding was encountered that is observed when liquids are boiled outside submerged tubes, where, because of excessive temperature difference, a vapor film forms and insulates the tube wall from the bulk of the liquid.

**Materials for the Construction of Chemical Engineering Equipment,** CHEM. & MET. REPORT, *Chem. & Met. Engr.* **49** (1942) pp. 85-128.

The war is having a tremendous effect on all materials, and in particular aluminum, stainless steels, nickel, copper, and rubber. The source of natural rubber is in the hands of the enemy, stainless steels are in demand for ships, guns, and tanks; copper for shells; aluminum for airplanes; rubber for jeep tires and a thousand other uses. Chem. & Met.'s 10th Materials of Construction issue presents the ways and means for conserving and protecting materials and equipment. Its data sheets bring up to date the basic information on manufacture, composition, corrosion and abrasion resistance. An effort has been made to make it a complete mobilization of available information. Properties of metals and alloys are presented on a series of fold-out inserts for simplicity in handling. For each material are given the manufacturer's name and address, the composition, and resistance to abrasion, to heat, and to commonly encountered chemicals. Among the materials included in the tabulation are chemical stoneware, porcelain, acid-proof brick and stone, cements and putties for acid-proof brick and stoneware, structural carbon and graphite, synthetic rubber, or rubber-like materials, plastics of many different types, glass, glass-lined and fused silica equipment, and wood of various types, as well as all of the metals and alloys.

**Formaldehyde from Natural Gas,** CHEM. & MET. PICTURED FLOWSHEET, *Chem. & Met. Engr.* **49** (1942) pp. 154-9 to 157-9.

The growing importance of the petroleum industry in the chemicals field is illustrated in the large-scale production of formaldehyde, methanol, and related chemicals by the direct oxidation of natural gas hydrocarbons at the Tallant, Oklahoma, chemical plant of the Cities Service Oil Company. The first successful commercial plant utilizing the direct oxidation of natural gas hydrocarbons was built at Tallant early in 1928. Since that time the production capacity of the plant has been consistently expanded. A substantially equal tonnage of methanol is produced simultaneously with formaldehyde. A somewhat smaller tonnage of acetaldehyde, methyl acetone and solvents is also produced. The process operates at moderate temperatures and pressures and does not require expensive forgings and other scarce materials essential to synthetic processes operating at high pressures. A flowsheet of the operation is given,

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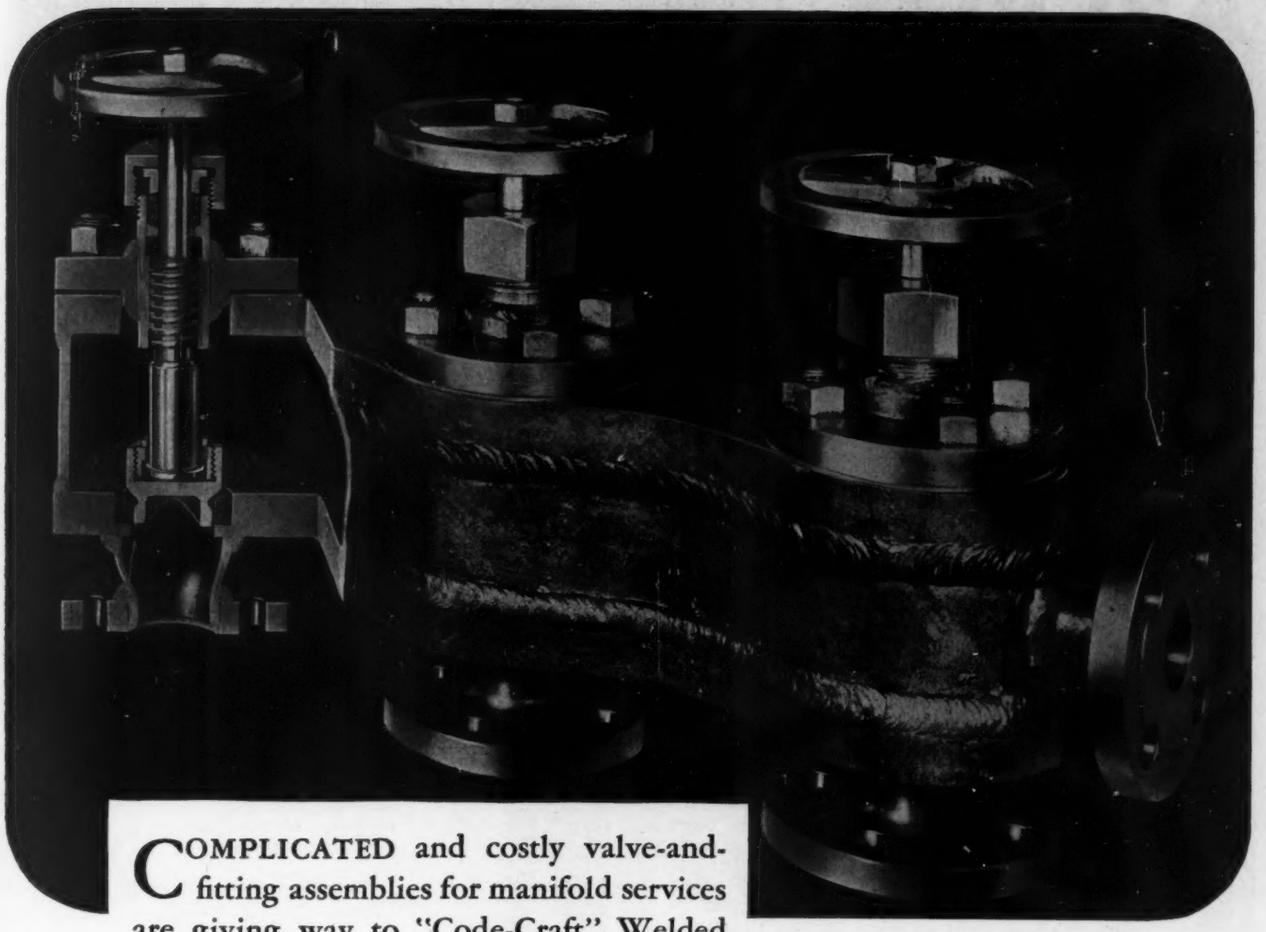

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| 1/2" | 13,468,000 | $1,481.44 | 1,219,280 | $792.53 | 1,524,100 | $243.86 |
| 3/8" | 7,558,500 | 831.44 | 684,290 | 444.79 | 855,360 | 136.86 |
| 1/4" | 3,366,990 | 370.37 | 304,820 | 198.13 | 381,020 | 60.96 |
| 1/8" | 824,570 | 90.70 | 74,650 | 48.52 | 93,310 | 14.93 |
| 1/16" | 213,000 | 23.43 | 19,280 | 12.53 | 24,110 | 3.80 |
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along with photographs showing the various parts of the flowsheet in pictorial form.

**A Convenient Graphical Method for the Valuation of Lubricating Crude Oils,** H. Moore, *Pet. Times,* Feb. 7 (1942) pp. 68-9.

A graphical procedure is described that allows the calculation of the viscosities of all the oils that can be prepared from a particular crude oil, without recourse to the blending of small fractions and retesting. Examples of the application of the procedure are presented. The market value of an oil is immediately obvious from a viscosity graph plotted in terms of volume percentages in the crude oil. By plotting the more important physical properties, a rough idea of flash point, specific gravity, and cold test can be obtained.

**Reclamation of Lubricating Oil in Britain a National Necessity,** R. B. Hobson, *Petroleum Times* **45** (1941) pp. 659-60, 679.

A process is described that was developed by Pressure Lubricants, Ltd., in which used lubricating oil is uniformly blended and settled to remove the major portion of mechanical impurities and water, and then purified by distillation in the presence of a compound that coagulates the finely divided carbon and other impurities remaining in the oil, and at the same time removes the acidic and oxidized substances generated during its use. Tables are given showing the properties of motor, transformer, aviation, and other oils before and after reclamation.

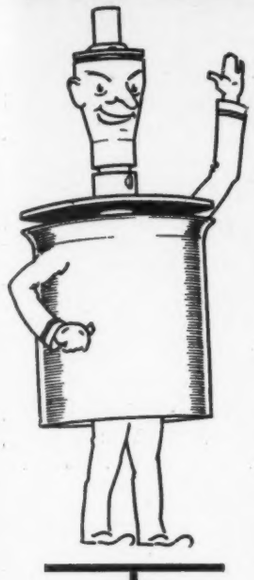
**Simplified Calculation of Theoretical Plates,** G. W. Thomson and H. A. Beatty, *Ind. & Eng. Chem.* **34** (1942) pp. 1124-30.

Simplified methods are presented for calculating the number of theoretical plates for the separation of a binary mixture containing less than 5 mole percent of one component. The assumptions involved are that the operating lines are linear and that the equilibrium curve is also linear near the ends of the x-y diagram. The data presented show that the number of plates calculated by these methods does not differ significantly from the number calculated by the exact Smoker equation or by the McCabe-Thiele graphical method. Methods that have been used for the calculation of theoretical plates are reviewed by the authors. This is followed by a derivation of their basic equation and by the application of their method to the solution of a typical problem. A bibliography of 16 references is included.

## Products: Properties And Utilization

**Acetylene as Motor Fuel,** N. C. Jones, *Chem. & Ind.* **61** (1942) p. 368.

Because of the serious shortage of motor spirit, portable acetylene gas generators are now being used in Switzerland and to some extent in France, to provide fuel for motor cars. At a recent motor show in Zurich, at least seven different types of acetylene generators were displayed. The generators are of the automatic type, and are divided into water - to - carbide and carbide-to-water



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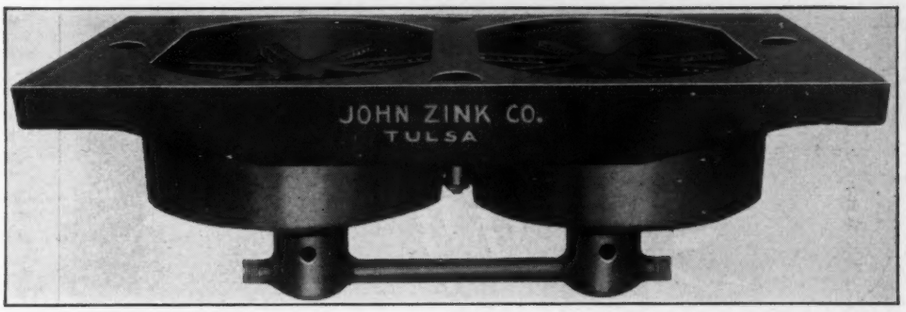


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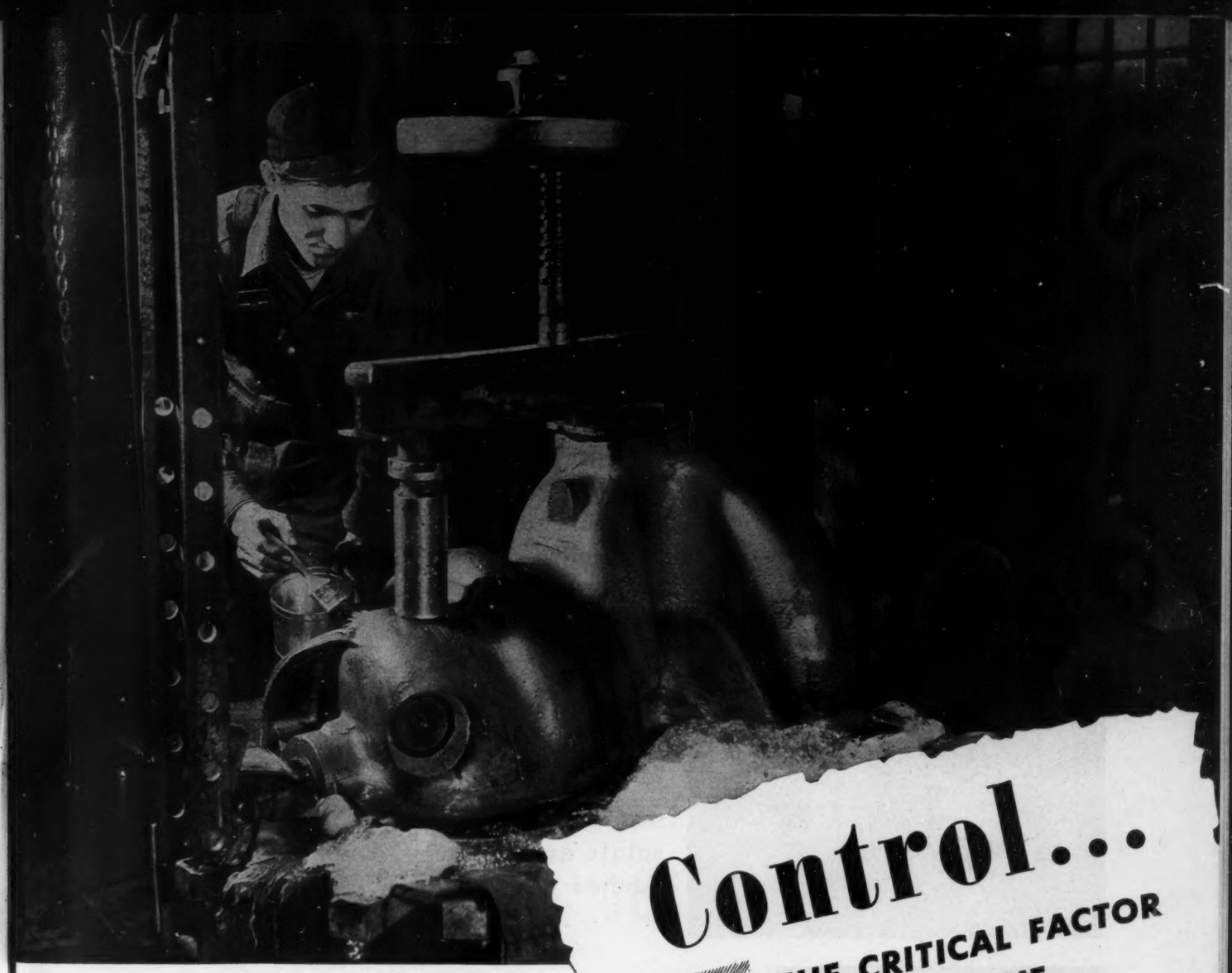
systems. A gasoline tank is frequently used as a water container, and water is delivered by the usual gasoline pump to the drip feeds to the carbide tank. Acetylene has a heat of combustion of 1440 B.t.u. per cubic foot, and a wide range of explosibility, from 3.35 to 52.3 percent of acetylene by volume. From the anti-knock angle acetylene is a poor motor fuel. It is usually improved by adding a little methyl alcohol with the gas. When using acetylene the speed of the car is reduced, but acceleration is good, and starting practically instantaneous. About 22 pounds of carbide produce acetylene equivalent to one gallon of gasoline. Running on 100 percent acetylene would be equivalent to paying 7 shillings per gallon for gasoline in Great Britain today.

**Substitute Fuels as a War Economy,** G. EGLOFF AND P. M. VAN ARSDELL, *Jour. Inst. Petr.* **28** (1942) pp. 115-132.

The estimated quantity of petroleum and substitute fuels produced throughout Axis Europe is approximately 11,268,000 barrels monthly. The invasion of Russia has cost Germany about 21,250,000 barrels of oil and substitutes per month. Thus Germany is using oil and its substitutes at approximately double the rate of the production capacity of the European continent. Axis Europe is short about 120 million barrels of oil per year, based on the Russian campaign. It has been estimated that oil stocks in Germany were approximately 60 million barrels without taking into account losses from aerial bombardment. Hydrogenation of coal by the Bergius, and carbon monoxide by the Fischer-Tropsch processes has formed the major source of substitute fuels in Germany. The Bergius process is the more important. Compressed gases are discussed, as well as gas-producer development. Power alcohols, both methyl and ethyl, are in use to some extent. The petroleum condition in Japan is considered in the article. The authors conclude that the relatively poor quality of the Axis fuels has curtailed the maneuverability of their automotive transportation, including airplanes. The successful conclusion of the war will be based largely on the superior quality and quantity of the motor fuels available to the United Nations in unlimited volume.

**Combustion in Diesel Engines,** M. A. ELLIOTT AND L. B. BERGER, *Ind. & Eng. Chem.* **34** (1942) pp. 1065-71.

In a Diesel engine air is drawn into the cylinder and compressed, and near the end of the compression stroke, fuel oil is injected into the combustion chamber under high pressure and in a state of fine subdivision. The temperature of the compressed air is such that autoignition of the fuel occurs and combustion ensues. Although every effort is made to inject the fuel in a fine spray and to attain uniform mixing with the air, the reaction materials remain far from being brought together in a state of molecular intimacy, and the ensuing reactions can be considered as starting in a heterogeneous mixture. The two processes go on side by side: (a) direct oxidation of the hydrocarbon fuel through a series of reactions in which intermediate, partly oxidized compounds are formed, and (b) thermal decomposition of the fuel followed by combustion of the destruction products. Chill-



# Control...

## THE CRITICAL FACTOR IN SUBMARINE OR STEEL CASTING

AMERICAN submarines—the "daggers of the Pacific" that have done so much damage to Japan's fleet and shipping—are outstanding examples of the importance of control. The submarine runs submerged . . . strikes unseen . . . fires accurately with torpedo tube or gun . . . only by the grace of its control instruments.

Just as control has become increasingly important in the *operation* of military equipment, control steps have become more and more necessary in its *manufacture.* At the Lebanon Steel Foundry, this fact is recognized . . . and governs the production of all Circle Ⓛ Castings.

Lebanon maintains complete departments for inspection and testing operations. X-Ray or Gamma Ray examinations are fitted to the service requirements of the various castings. Special tests are frequently made at the customer's request.

All pressure castings are tested for possible leakage points. Castings are set up with all ports and openings blanked off. The castings are then filled with water (for hydrostatic testing, as illustrated), oil or compressed air. A specific pressure is applied and maintained for a specified time. The outside surfaces are closely studied for evidence of leakage.

Victory demands castings of the highest integrity . . . and Lebanon provides them by paying the premium of close control. That's why Circle Ⓛ Castings have been "cited" for distinguished service in this toughest of wars . . . that's also why they are specified by such important industrial companies as De Laval and Leslie.

**Lebanon metallurgists have had close contact with war production requirements since the beginning. Their experience in solving today's type of industrial problem is available to interested organizations.**

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The Butterfly Valve is controlled automatically by the tank float and is actuated by the hydraulic power cylinder attached to the valve.

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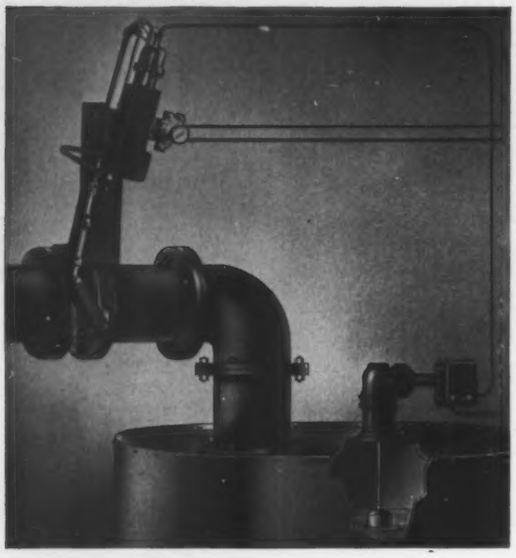

R-S Butterfly Valves provide *simplified* control and wedge-tight shut-off of volume and pressure for air, steam, oil and other liquids—in fact, any material that flows or is forced through a pipe. Constructed to withstand high temperatures and pressures to 600 pounds.

Write for detailed information and Catalog No. 10-B.

*Direct action float control for low working pressure. Can be furnished with counter weight assembly or larger floats as required.*

BUTTERFLY VALVE DIVISION

**R-S PRODUCTS CORPORATION**

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R-S Streamlined BUTTERFLY VALVES


ing of the direct-oxidation reactions will result in the presence of carbon monoxide and aldehydes in the exhaust. The presence in the exhaust gas of any product of incomplete combustion when the quantity of air present is more than enough for complete combustion indicates either (a) chilling of combustion reaction or (b) the existence of other conditions unfavorable to complete reaction with oxygen. Consequently, evaluation of the products of combustion furnishes information on the nature of the combustion process in Diesel engines. In a study of the effects on exhaust gas composition of adding natural gas to the intake air of two commercial Diesel engines, information was gained incidentally on combustion phenomena in this type of engine. The results furnish considerable data on the mechanism of combustion in the Diesel engine and suggest the value of adding combustible gases to the intake as an experimental technique for studies in this field. Evidence is presented indicating the importance of an effect analogous to the lower limit of flammability in relation to combustion in the Diesel engine. The existence of overlean regions in which flame does not propagate is discussed, and evidence is offered indicating that such regions probably are the source of carbon monoxide and aldehydes in the exhaust gas at fuel: air ratios less than the chemically correct value.

**Determination of Water in Insulating Oil,** R. N. Evans and J. E. Davenport, *Ind. & Eng. Chem.,* Anal. Ed. **14** (1942) pp. 732-3.

It has been shown through study of the electric hydrometer that because of an indeterminate hysteresis effect the hygrometer unit cannot be used to determine the water content of insulating oil. However, in the course of this work a constant-volume or manometric procedure was devised that shows promise as a rapid and accurate procedure for the determination of small quantities of water in oil. The method involves the taking of two pressure readings—namely, the initial pressure of the gases removed by evacuation of the oil sample and a final pressure reading after exposure of the evolved gases to a film of lithium chloride monohydrate. The method is described in detail in the article, and a diagrammatic sketch of the apparatus is included. A table is given that shows a comparison of the results obtained by the manometric method and the combustion procedure. The apparatus has been designed so that water can be determined in concentrations ranging from 8 to 170 parts per million, using a 30-gram sample.

**Some Aspects of Industrial Lubrication,** Hund, Larsen, Beeck and Vesper, Shell Development Co., *Mech. Engr.* **64** (1942) pp. 525-30.

It is known that in boundary lubrication, the coefficient of friction is substantially independent of the viscosity of the oil and of the velocity of sliding. The low coefficient of friction obtained at relatively high velocities must be the result of a state of quasi-hydrodynamic lubrication or a "wedging effect," caused by surface activity of the oil and requiring the presence of sufficient quantities of oil to be wedged. This has been confirmed by the discovery that monomolecular layers of polar materials do

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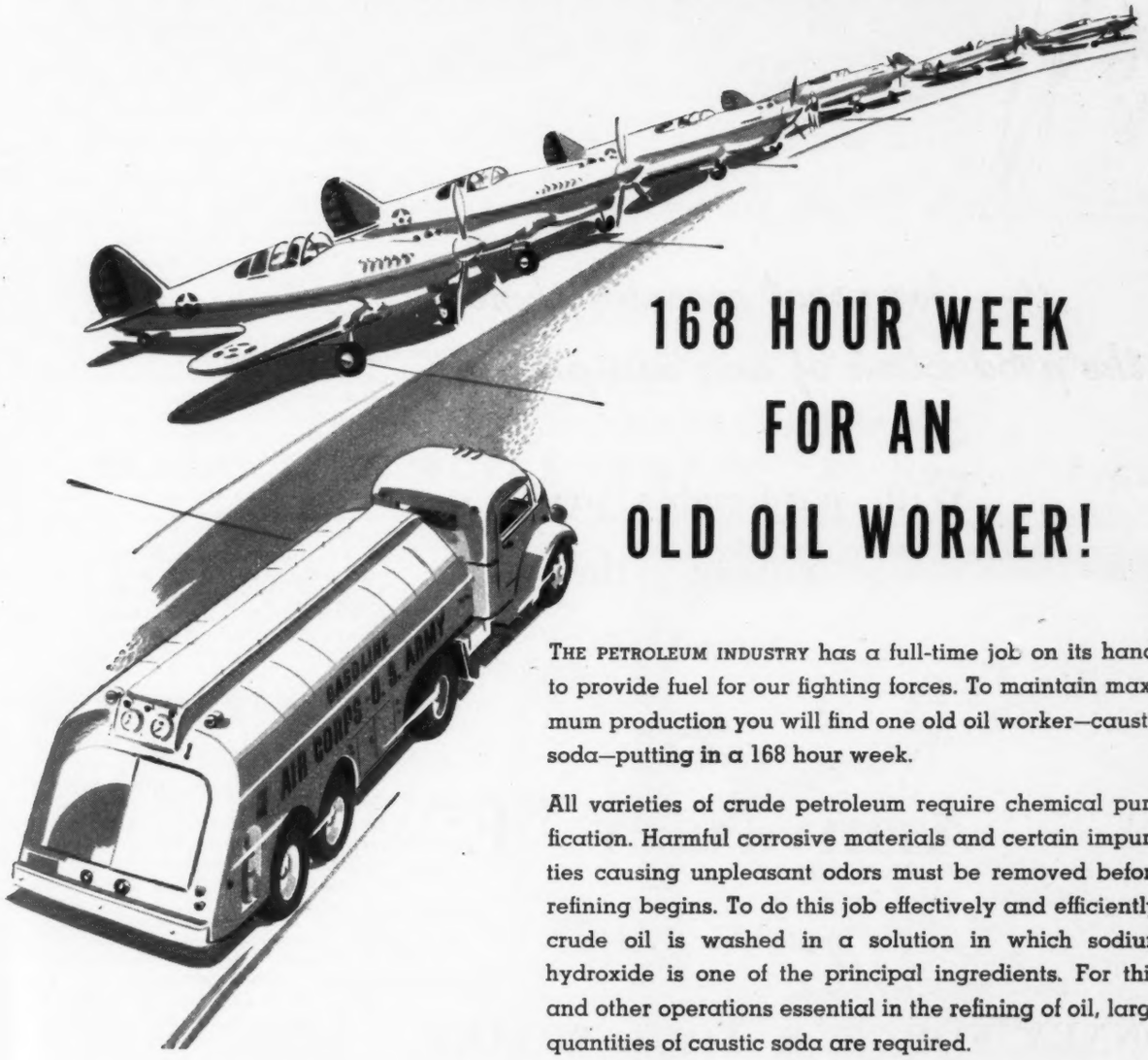


## 168 HOUR WEEK FOR AN OLD OIL WORKER!

THE PETROLEUM INDUSTRY has a full-time job on its hands to provide fuel for our fighting forces. To maintain maximum production you will find one old oil worker—caustic soda—putting in a 168 hour week.

All varieties of crude petroleum require chemical purification. Harmful corrosive materials and certain impurities causing unpleasant odors must be removed before refining begins. To do this job effectively and efficiently, crude oil is washed in a solution in which sodium hydroxide is one of the principal ingredients. For this, and other operations essential in the refining of oil, large quantities of caustic soda are required.

This is only one of the many industrial uses of caustic soda. It is equally essential for the production of rubber, textiles, soap and plastics. Dow has long been one of the major producers of this indispensable chemical and American industry continues to draw heavily on Dow for its caustic soda requirements.

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**September 5, 1942**

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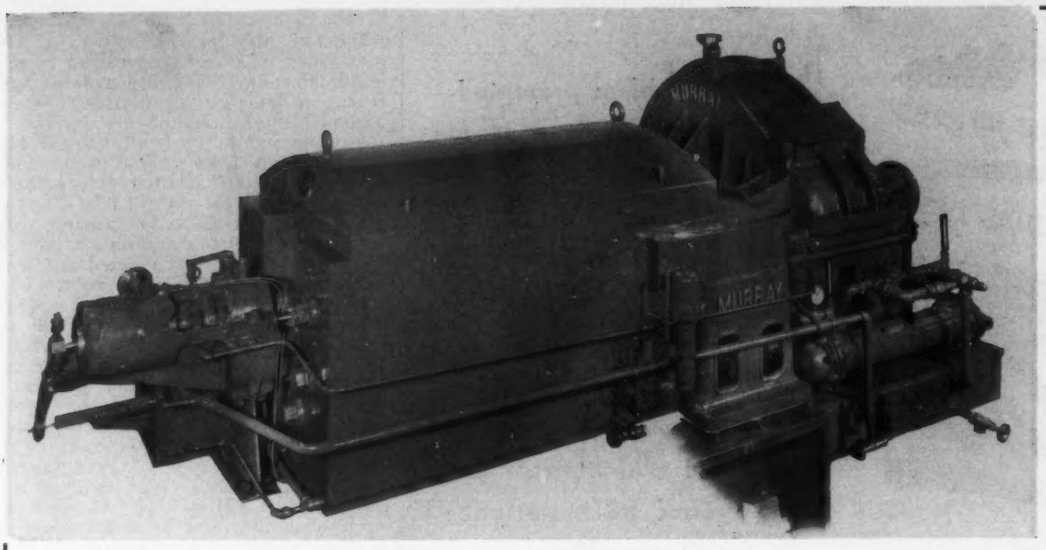
not show the effect, but that it is shown in flood lubrication. All substances that show a wedging effect had a highly oriented surface structure. By using the four-ball machine, a group of chemical compounds was found that enabled wear to be kept low by keeping the rubbing surfaces polished. Tricresyl phosphate is the best-known of this group of substances. The hot high spots of the metal react with the phosphorus compound and form a phosphide. This alloys with the metal and lowers the melting point so that the metal flows into the valleys and the surface becomes highly polished. Extreme pressure agents are distinguished from the chemical polishing agents by their leaving of a surface film such as a sulfide or chloride that prevents the metals welding together. Pressure increases the viscosity of an oil greatly. At 20,000 pounds per square inch the viscosity may be 200 times as great as it is at atmospheric pressure.

**Oxidation of Asphalt in Thin Films,** A. R. EBBERTS, *Ind. & Eng. Chem.* **34** (1942) pp. 1048-51.

For several years many investigations in the field of bituminous pavements have been concerned with the hardening of the bitumen with age and particularly in the mixing operation. There is considerable evidence that the major factor in this hardening is oxidation. A method for measuring the oxidation of asphalts in thin films by means of potassium permanganate has been devised. It is fast and precise, and requires no special apparatus. Correlation with pavement service has been established in several instances. The procedure is described, and the results of the examination of various types of asphalts are shown graphically. The effect of air blowing on asphalts is still obscure. The permanganate oxidation method will distinguish between asphalts cracked at different levels, and shows clearly the long known fact that cracking increases susceptibility to oxidation.

**Synthetic Soap,** *Industrial Chemist,* **18** pp. 284-9.

The Shell Group has conducted intensive research on the production of synthetic detergents or surface active materials from petroleum products. This research has culminated in the development of processes for producing the sodium salts of higher secondary alkyl sulphates synthesized from by-products of petroleum refining. A plant has been erected in England in which sodium alkyl sulphates are being manufactured on a large scale. The essential characteristic of a detergent molecule is a long carbon chain and a water soluble polar group. As a result of this structure such compounds tend to concentrate at the oil/water interface. The detergent properties of a given substance are largely dependent on the ability of the molecule to distribute itself across the interface. The carboxylic acid soaps possess disadvantages in that they are hydrolysed in solution and that the calcium soaps are insoluble in water. Also, they cannot be used in solutions of low pH. Many attempts have therefore been made to produce detergents possessing improved stability to hard water and to low pH. Among other well-known modern developments in synthetic surface active products are the alkyl aryl sulphonic acid salts, as for example isopropylnaphthalene sulphonic acid, and also the



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**STEAM CONDITIONS: 160 lb., 100° F.; S.H., 28″ Vac.**

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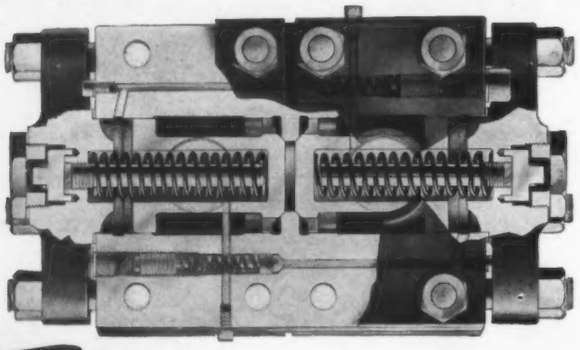

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sulphated primary alcohols. The first mentioned, although possessing considerable wetting power, are generally deficient in detergent properties. The sulphated primary alcohols are derived directly or indirectly from natural fats. The particular importance of the Shell development is that their detergents in no way depend on natural fats. The raw material is cracked under carefully controlled conditions to produce a mixture of olefines that is fractionated and from which a special cut, possessing the optimum balance between wetting and detergent properties, is isolated. This cut is treated with acid under strictly controlled conditions whereby a crude sulphated product is obtained. This, after neutralization, is subjected to special purification processes. The final product is a mixture of the sodium salts of the corresponding secondary alkyl sulphates. It is marketed as a clear liquid of pale yellow color. Below 15/20° C. the liquid becomes cloudy and at still lower temperatures there is a tendency to gel. It is expected that the products of this type will have wide use in the textile industry.

**A Comparative Study of Oils for Supplemental Protection of Black Oxide Coatings on Steel,** E. A. PARKER AND A. K. GRAHAM, *Metal Finishing* **40** (1942) pp. 363-44, 367.

The oils used in the study were straight mineral oil, with and without additions of inhibitors, fatty acid type oils, antirust compounds of the solvent type, and water-soluble oils. The soluble oils were employed as water emulsions at 180° F. with 50 percent oil by volume in the emulsion. The soluble oils were found to be superior to the other types. The time required for slight rust to appear ranged from 25 to 300 hours, while with solvent oils with resin base it ranged from 22.5 to 34 hours, with straight solvent oils from 18 to 31.5 hours, and with mineral oil without inhibitor the time for rust to appear was only 2 hours, with inhibitor 23 hours.

## Specifications Announced For Pooled Products

New minimum specifications which will apply to all gasoline, kerosine, distillate and residual fuel oils delivered in the East under the "pooling" system estabished by Directive No. 59 were announced by OPC October 28.

As previously disclosed, the minimum gasoline specifications call for 80-octane for premium, the quality necessary to meet Army requirements, and 72-octane for regular or house brand, with no specification for third grade.

The minimum specification for kerosine has been set in accordance with the standards of the Treasury's procurement division (VV-K-211a), which applies to purchases for the Army and Navy, and Commercial Standard CS12-40, set up by the industry several years ago and adopted as the basis for all fuel-oil specifications, including those for Army and Navy purchases, will be applied to fuel oil.

OPC reassured the public that the new specifications will cause no undue hardship and, in a message to the industry, pointed out that they apply only to products imported into or produced in the Eastern States.

# *New power for fighters*

Cumene is a new word in the refining language but it is a mighty important one

It is the name of a new and vital war product—a blending fluid that punches holes in the 100-octane ceiling for aviation gasoline and carries its quality on up

It gives new lifting power to our fighting flyers—they need it in enormous volume

U.O.P. catalytic polymerization units can be changed over from the production of polymer gasoline to the production of cumene—they are being converted now

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Chicago, Illinois

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Owner and Licensor

THE REFINERS INSTITUTE OF PETROLEUM TECHNOLOGY

# NEW EQUIPMENT FOR THE MODERN PLANT

## Stress Relieving Unit

**H. O. SWABODA, INC.**

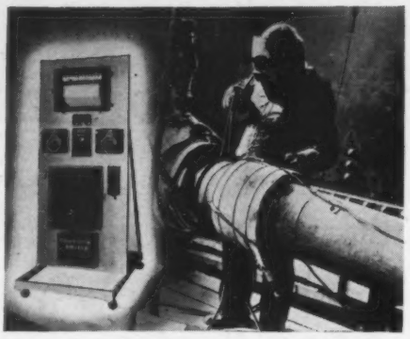
H. O. Swaboda, Inc., New Brighton, Pennsylvania, has designed a electric preheating and stress-relieving unit for field welds in pressure piping.

The units are a wrap-around type consisting of resistance wire sheathed in refractory insulation. Two of these units are wrapped about the pipe, one on each side of the joint, for preheating. After the weld has been made, a third unit is wrapped directly over the weld to create a uniform temperature sufficient for stress-relieving over the entire joint including distance in excess of six times the pipe wall thickness at each side of the joint. Heat radiation is held to a minimum by a wrapping of asbestos or similar insulation.

Of primary interest, is the automatic control panel, which, by the means of thermocouples, records and controls the individual point temperatures. The thermocouples are attached to each side of the pipe joint and directly to the weld. Direct connection between the temperature controlling instrument and each heating unit, through a magnetic contactor, regulates the energy input and assures uniform heating.

By means of adjustments provided on the automatic control panel, it is possible to preset the complete process of heating, soaking, and cooling, and simultaneously and automatically increase the heat to stress-relieving temperatures at a predetermined rate. After reaching the desired temperature, the control automatically adjusts itself to hold a given temperature for any predetermined time and gradual recession of heat to the desired temperature at a given rate then automatically takes place, after which the control shuts itself off.

A range of 8 sizes of heaters will accomodate pipe from 1½ inches to 24 inches. Various combination uses of sizes permit treating any type joint including pipe-to-fitting and pipe-to-valve joints. Highly satisfactory results have been recorded using the same equipment for both plain carbon steel and alloys, including carbon-molybdenum and similar types.



Swaboda Stress Relieving Unit

## Dust Respirator

**MINE SAFETY APPLIANCES COMPANY**

Mine Safety Appliances Company, Braddock, Thomas and Meade Streets, Pittsburgh, has redesigned the filter cases of its Comfo Dust Respirator from black plastic to conserve metal. As described by the company the new design offers better appearance and less resistance to air flow. The new filter-container units are thinner, with rounded edges, which permit better vision.

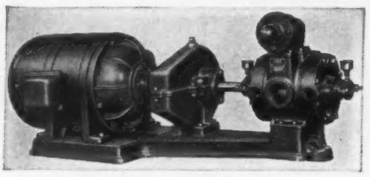
The redesigned cases have high impact strength with no electrical conductivity. They are not effected by perspiration. The plastic model has twin side-placed replacable filters. The unit is easy to clean. It is available in types to meet various dust and mist conditions.

## Steam Jacketed Pump

**BLACKMER PUMP COMPANY**

Blackmer Pump Company, Grand Rapids, Michigan, has introduced a steam-jacketed pumping unit for handling tar, grease and similar products, which must be processed or transferred while hot. Its heads are of cast semi-steel with threaded intake and exhaust ports and drain plugs. They are suitable for pressure up to 125 pounds.

Sleeve bearings are grease lubricated and located outside the pump casings. This heavy bearing construction eliminates shaft whip and distortion. Pumps for pressures in excess of 100 pounds are furnished with anti-friction bearings. Stuffing boxes are deep with ample number of packing rings. Stuffing box glands are the bolted type with back-off nuts to make repacking a simple job.



Blackmer Pump

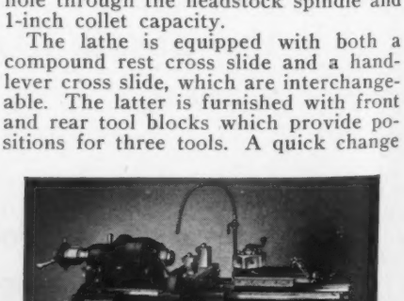
The pumps are available in capacities from 20 to 700 gpm and pressures up to 300 pounds per square inch are available with the steam-jacketed head. They are furnished with either single- or double-reduction gear drive and as single- or multiple-pumping units.

## Floor Type Lathe

**SOUTH BEND LATHE WORKS**

South Bend Lathe Works, South Bend, Indiana, has introduced a new floor-type turret lathe for rapid production work to close tolerances of small chucking or bar work. Second operation work can be handled efficiently. This lathe has a 10-inch swing over the bed or saddle wings, a 1⅜-inch hole through the headstock spindle and 1-inch collet capacity.

The lathe is equipped with both a compound rest cross slide and a hand-lever cross slide, which are interchangeable. The latter is furnished with front and rear tool blocks which provide positions for three tools. A quick change



Floor Type Lathe

# Frequent inspection keeps equipment operating

*This information supplied by "Petroleum Refiner"*

An effort to obtain longer life from refinery equipment imposes increased attention on inspection.

Even the plant with the perfect pre-war inspection department finds itself faced with a stepping up of inspection routine. Practically everything now calls for intensified inspection — stills, heating units, compressor plants, refrigeration equipment, boiler and power plants, all forms of handling equipment, tankage and firefighting apparatus and systems.

Friction, rust, heat and corrosion are the common and constant foes of the petroleum refiner.

Large plants have long had inspection organizations. Smaller plants need them now as never before.

Organization of an inspection service is essential. A typical organization calls for a chief inspector having under him (1) Mechanical Inspectors who inspect plant equipment periodically using approved methods, (2) Engineering Assistants who set schedules, receive reports, correlate data and make calculations, (3) Clerical help to handle mechanical office work.

A general rule among inspection departments is that a plant inspector must not be afraid of dirt. He has to "get in there and see for himself". An inspection job can be properly performed in no other way.

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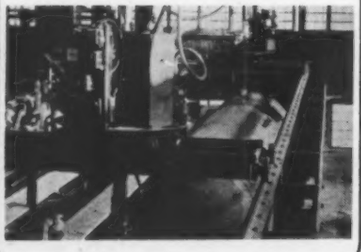

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gear box supplies 48 longitudinal power feeds for the universal carriage, 48 power cross feeds for the compound rest cross slide, and 48 thread cutting feeds, 4 to 224 per inch. The hand-lever operated bed turret indexes automatically and has an adjustable stop for each of the six turret tool positions. The underneath motor drive and back gears deliver twelve spindle speeds ranging from 50 to 1357 r.p.m. The lathe is available either with or without coolant equipment.

Tooling for special work or second operation jobs is simplified by a large assortment of attachments and accessories.

## Welding Electrode

**AIR REDUCTION SALES COMPANY**

Air Reduction Sales Company has developed a new electrode designed specifically for all-position welding of mild steel with A-C type welding machines in following diameters: ⅛-inch and 5/32-inch.

Made to fill a rapidly-growing need for a high quality A-C electrode for all-position use, the Airco No. 230 electrode complies with all requirements of the American Welding Society Classification E6011, American Bureau of Shipping, Group H1G and B1G for A-C and other specifications qualifying it for use on war work.

Physical tests demonstrate that this electrode gives exceptional satisfactory results. The high quality of deposited metal of the No. 230 is fully comparable to that of the best D-C reverse polarity all-position electrodes.

Following are physical test results made on all-weld-metal tensile specimens:

Ultimate Tensile Strength, as welded, 70,000-75,000; stress relieved, 65,000-70,000. Percent Elongation in 2 inches, as welded, 25-30 percent; stress relieved, 30-35 percent.

An outstanding characteristic of this A-C electrode is that average operators have no difficulty in securing good fusion and complete penetration. The finished weld deposit is quite smooth and has a uniform surface contour.

## Welding Arc Control

**WILSON WELDER AND METALS COMPANY**

Wilson Welder and Metals Company, 60 East Forty-second Street, New York, has developed the Honey Bee Arc Control Station for increasing welding output per machine, better control by the operator and improvement on welds on thin gauge metal.

These units are made in capacities of 75 amperes and 150 amperes. They are an auxiliary electric device, connected in series with the welding circuit of any constant potential arc welding generator. Most conventional drooping voltage generators can be converted quickly and easily to constant potential. For this purpose, a quick change switch is mounted on the generator. A portable switch held in the operator's hand gives the operator remote control of the welding current within predetermined limits. This switch may be combined with the electrode holder, if desired.

**Three Wilson arc control stations attached to a Wilson welder.**

When two or more Arc Control Stations are hooked up to a single generator, a like number of welding arcs can be operated simultaneously. Each operator can regulate his own current and weld as he sees fit without affecting the other in any way. One of the important features of this new arrangement is the remote control of the arc when the operator reaches the end of a bead, thereby enabling him to greatly improve the quality of the weld deposit at the crater. This is accomplished by gradually reducing the current which, in turn, reduces the heat and avoids porous, cracked craters and inclusions. Each operator has his choice of two methods of control:

He can set his control to deliver a definite current at the arc and weld steadily at that setting. He can use the hand switch to vary the current without breaking the arc. This enables him to start his arc on cold metal with a maximum current (hot arc) and to reduce the current as the work warms up.

Using two 75-ampere arc-control stations, a 200-ampere generator can serve two operators instead of one.

## Pressure Transmitter

**COCHRANE CORPORATION**

Cochrane Corporation, Seventeenth and Allegheny Avenue, Philadelphia, has a new transmitter for use with its standard electric meter receiving units and designed specifically for the measurement of low static pressure gases where low differential and resultant low permanent pressure loss is of importance.

Differential pressure created by flow is applied to the opposite sides of the oil-sealed bell with the pressure from the connection before the primary element being applied under the bell and the downstream pressure above the bell. A metallic displacer in the central reservoir is submerged in mercury to a point where the bell and displacer just float when no differential pressure is exerted. A flow of gas resulting in a change of differential pressure raises the bell, lifting the displacer from the mercury with the change in buoyancy being just sufficient to give a bell movement proportional to the differential pressure. The translation of bell movement to uniform-chart readings is accomplished by the individually calibrated cam common to Cochrane receivers.

The Style H transmitter is designed for differentials of 2, 4, 6, 8, or 10 inches of water. Standardization of design permits altering the differential head by changing the displacer and amount of mercury in the central reservoir. The bell casing is designed for a maximum working pressure of 75 pounds per square inch.

Differential pressure in excess of the

design differential will move the bell to its upper limit, and the gas will bubble out from under the bell with relatively little disturbance because of the large volume of bell in comparison to the size of high pressure inlet pipe. Normal operation of the meter is resumed upon the differential falling to normal values.

Ease of accessibility to the transmitter interior permits quick and thorough cleaning of all parts, an operation made often necessary on blast furnace and coke oven gases. Sealing oil level can be quickly checked through the filling plug without removal of the top cover. The same mounting bracket can be used in either wall or floor mounting of the unit.

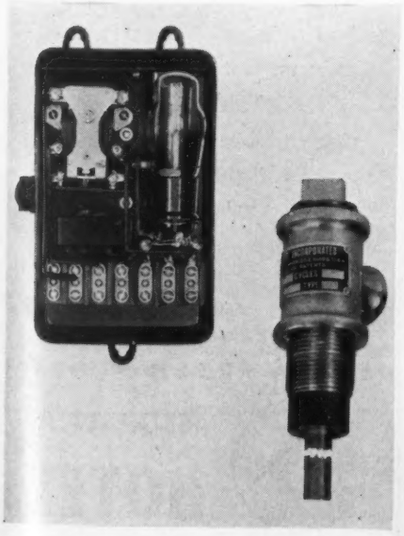
## Water Detector Lock

**PHOTOSWITCH INCORPORATED**

Photoswitch, Incorporated, 21 Chestnut Street, Cambridge, Massachusetts, has designed an Electronic Water Detector Lock Type P15NH to indicate water seepage in gasoline storage tanks. It is supplied with probe fitting type E31.

The probe fitting is mounted in a standard pipe fitting on the top surface of the tank, the probe rod projecting down through the tank to the level at which water seepage is to be detected—usually three inches from the bottom of the tank. Electronic Water Detector Lock Type P15NH is located at any point remote from the tank and wired to the probe. While the probe rod is entirely immersed in gasoline and as long as water seepage has not reached the probe, no signal is given. When water seepage rises to contact the probe tip, an electrical circuit is completed through the water itself, and the Water Detector Lock operates, turning off pumping equipment and actuating an alarm circut. It operates on 115 or 230 volts A.C. Battery-operated P15NB is also available as standard.

The unit will handle output loads up to 10 amperes at 115 volts A.C. It is supplied in a weather-proof, pressed-steel housing, finished in green crystal. Explosion-proof housings are also available. Probe fitting Type H31 is furnished in brass, stainless steel, and other metals.



Photoswitch Water Detector


NEW FLUORESCENT GREEN H W

TO OBTAIN CAST!

Here is an effective additive that gives your lubes a natural bloom . . without affecting their fire, flash, pour or carbon tests. The use of New Fluorescent Green H W also speeds production because there is no tie-up of equipment, no extra labor that blending demands.

What's more, lube oils treated with this 100% synthetic compound are stable to light, heat and storage.

Wilmot & Cassidy products have been used and approved by leading refiners for over a decade.

● Send for samples, prices and information.

WILMOT & CASSIDY, INC.
108 PROVOST STREET · BROOKLYN, N. Y.

**Great Jumping JEEPS!**

**MEET THE ARMY'S MECHANICAL MULE . . .**

**The Jeep—our Army's mechanical mule, has achieved a reputation of out-climbing, out-pulling and out-maneuvering anything of its weight ever put on four wheels. On every war front in the world, the Jeep is now the pride and joy of Brass Hats and Buck Privates alike.**

**But remember the men who build the Jeeps—those who train to operate and follow them—and the millions of others who are engaged in our war effort. For all, there had to be an abundance of water. It was the Layne Organization, who in the majority of cases, drilled the wells and built the systems that provide water by the millions of gallons. To a well water system, the name Layne is as famed as is the name Jeep to a four wheel vehicle.**

**Layne's reputation like that of the Jeep has been won on the field of action. Throughout the entire Nation, Layne wells and pumps are doing a magnificent job —providing water for ordnance plants, munition factories, training camps, air fields, ship yards and all kinds of war material producers. For late bulletins, address,**

**LAYNE & BOWLER, INC.**
**Memphis, Tenn.**

**LAYNE**
**PUMPS & WELL WATER SYSTEMS**

*Affiliated Companies*

Layne-Arkansas Company.....Stuttgart, Ark.
Layne-Atlantic Company.....Norfolk, Va.
Layne-Bowler New England Corp..Boston, Mass.
Layne-Central Company.....Memphis, Tenn.
Layne-Northern Company.....Mishawaka, Ind.
Layne-Louisiana Company.....Lake Charles, La.
Louisiana Well Company.....Monroe, La.
Layne-New York Company.....New York City
Layne-Northwest Company.....Milwaukee, Wis.
Layne-Ohio Company.....Columbus, Ohio
Layne-Texas Company.....Houston, Texas.
Layne-Western Company.....Kansas City, Mo.
Layne-Western Co. of Minn.....Minneapolis, Minn.
International Water Supply, Ltd...London, Ont.

WORLD'S LARGEST WATER DEVELOPERS

# ☆ BUSINESS NOTES ☆

## Sessions Joins Brown Fintube Company

Robert C. Sessions of the consulting engineering firm of Sessions & Sessions, Cleveland, Ohio, has been appointed chief engineer of The Brown Fintube Company, Elyria, Ohio.

R. C. SESSIONS

Sessions, who is a member of ASME and AIEE, was graduated from Worcester Polytechnic Institute in 1919 in electrical engineering. He was a fellow of the American Scandinavian Foundation in Sweden during 1919 and 1920, and was for some time in charge of the engineering and experimental division of Steel & Tubes, Inc. before entering consulting work. The firm of Sessions & Sessions, consulting engineers, is being continued with offices in the Rockefeller Building, Cleveland, under the active direction of Frank L. Sessions, senior partner of the firm.

## Pittsburgh Steel Makes Promotions

Recent promotions in the sales organization of Pittsburgh Steel Company, Grant Building, Pittsburgh, have been announced.

Henry A. Roemer, Jr., who has been manager of sales of steel and wire products, becomes assistant general manager of sales.

Norman F. Melville, who has been assistant, was advanced to manager of sales of steel and wire products.

## Shaw Joins Keystone Carbon Company Staff

George B. Shaw has been appointed sales engineer for Keystone Carbon Company, Saint Mary's, Pennsylvania. He will devote his efforts largely to promotion of Keystone Negative Temperature Coefficient Resistance Material, a recent development of the company. Shaw is a graduate of St. Francis College.

## Wins First Bond In Slogan Contest

Winner of the first prize war bond in the production slogan contest of employes of Leeds & Northrup Company, Philadelphia, was John T. Nevitt, Jr., an inspector. His slogan was "V Depends on Me." In the picture he is shown receiving the award from C. S. Redding, president of the company.

John T. Nevitt, Jr., receiving award from C. S. Redding, president, Leeds & Northrup Company.

This contest was one of the activities of the Joint Labor-Management Committee, which Leeds & Northrup set up immediately after the War Production Board suggested such committees for all plants producing war goods. The contest produced over 65 entries for every 100 employes. Promotion material consisted of posters on bulletin boards, and pay-envelope enclosures. In addition to first and second grand prizes, there were first prizes in war bonds for each departmental group of less than 100 persons, and both first and second prizes for groups of over that number. Contest was open to employes only.

## Contest Announced On Salvage Methods

Metallizing Engineering Company, 21 Forty-first Avenue, Long Island City, New York, has announced a contest with prizes totaling $650 in War Bonds on methods of maintenance and salvage procedure with the metal-spraying process. Complete details can be had from the company. The contest closes December 15.

The first prize will be $250, second $150, third $100 and three prizes of $50 each.

## Pfaudler Names Three District Representatives

The Pfaudler Company, Rochester, New York, announces the appointment of three new field representatives, all of whom are qualified by training and

**Why play blindman's buff?**

"Some people waste a whole evening trying to find a 'nice,' 'cheap' place to stay. Not me! I pick out a good hotel and my worries are over. Everything I need is right at my elbow."

J. D. FINDLAY,
Raleigh, N. C.

**AMERICAN HOTEL ASSOCIATION**

**FOR A FRESH START**

**STOP AT A HOTEL**

ROBT. VAN IDERSTINE

JOHN PONTIUS

JOHN LAMBERT

experience to handle today's special war service requirements.

Robert Van Iderstine, St. Louis representative, was formerly with the Barrett Division of Allied Chemical and Dye Corporation, New York City. He is a graduate chemical engineer with degrees from Columbia University, New York City, and the Polytechnic Institute of Brooklyn.

John A. Pontius, with headquarters in Minneapolis, was formerly with the York Ice Machinery Corporation as service engineer in the dairy equipment division. He is a graduate of Ohio State University.

K. J. Lambert, a member of the Chicago sales staff of The Pfaudler Company, was formerly with Cherry-Burrell Corporation. He is a graduate of the University of Illinois where he received a B.S. degree in mechanical engineering.

### Putman Vice President Of Westinghouse Company

H. V. Putman, manager of the transformer division of Westinghouse Electric and Manufacturing Company, East Pittsburgh, has been elected a vice president. He has been manager of the transformer division for two years and its output has more than doubled in that period.

Putman had his college training through that of doctor of philosophy at Union College, Schenectady, New York. Two years after finishing his education he joined the Westinghouse staff as a design engineer on synchronous motors.

### Army-Navy Award To Duriron Company

The "E" Award of the Army-Navy was made to employes of Duriron Company, Inc., Dayton, Ohio, October 8. The award was conferred September 12 and made by Lt. Com. L. F. Adams, U.S.N., who presented pins to all employes.

### Tube Turns, Inc. Gets E Award

Tube Turns, Louisville, recently won the distinction of being the first war industry plant in Kentucky to receive the coveted Army and Navy "E" flag for outstanding production efficiency.

National, state and local industrial and military leaders attended the brief, colorful ceremonies at the plant on September 18, at which the award was presented before a crowd of more than 3000 employes and their families. Individual Army-Navy "E" pins were later distributed to every employe.

Characteristic of the nation's aroused industrial might, W. H. Girdler, president of the company, said in accepting the award, "we have just begun . . . our production in the next 12 will be three times more than in the past 12 months!"

The employe representative selected to receive the individual Army-Navy "E" pins, on behalf of all employes, declared significantly, "you haven't seen anything yet!"

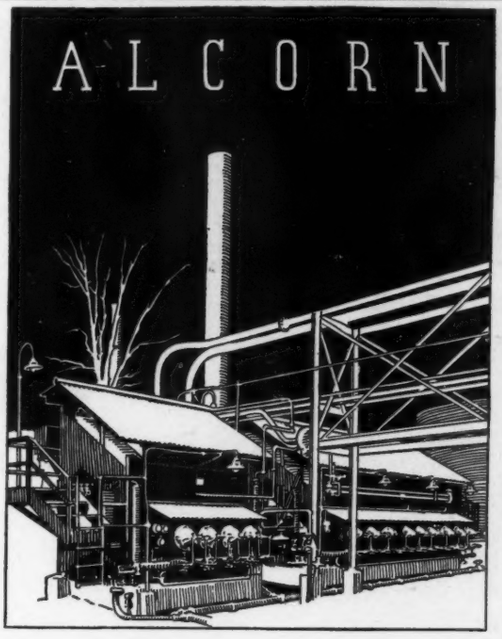
### Kieley and Mueller Increases Factory

Kieley and Mueller, Inc., has expanded its factory to triple the size of the former plant at Newark, New Jersey. The new factory and general offices, including properties, cover a whole city block at North Bergen, New Jersey.

The expansion had been contemplated prior to the war activity and became an urgency as the call for war materials was made.

Many innovations are included in the production of regulating valves, strainers, back pressure valves, as a near approach is made to the belt system of assembly. Rolling racks are used, which stay with the parts until the valve is finished for test and shipping.

Special boiler test equipment has been


LOW TEMPERATURE...OR HIGH...
HEATERS MUST BE DEPENDABLE

**EVERCHANGING demands on petroleum products continuously evolve new processes. Alcorn, a pioneer in heating, has seen many improvements in methods, has developed many of these improvements. One thing, alone, has remained constant—success in operation and economy of result are secured only by the most efficient heating. This, in turn, is possible only through good engineering and experience.**

ALCORN COMBUSTION COMPANY

SCHAFF BLDG., PHILADELPHIA

LOS ANGELES HOUSTON SAN FRANCISCO

installed as well as many special production machine tools.

A mezzanine floor, from which semi-complete castings feed the production floor, materially aids in the output so vital today.

### H. L. Watson Heads De Laval Company

H. L. Watson, who has been executive vice presient of De Laval Steam Turbine Company since 1934, has been elected president to succeed Francis J. Arend, who died in August of this year.

From 1913 to 1934 Watson was general sales manager. He was graduated from Rose Polytechnic Institute in 1915 and served as erecting engineer and later in steam turbine sales work with Allis-Chalmers Manufacturing Company previous to his connection with the De Laval organization.

### E. D. Bullard Company Changes Denver Address

The Denver office of E. D. Bullard Company has been changed to 18 Wazee Market. The former address was 56 Wazee Market. Howard Timms, who has been in charge of this office since the resignation of Tom Hallinan remains as district manager for Colorado and Wyoming.

### Foote Bros. Announces Sales Department Changes

Foote Bros. Gear and Machine Corporation, Chicago, announced the election of Russell G. Davis, a vice president. He will continue in his capacity of general manager of the industrial gear division.

In line with the recently vastly increased business of this company, a number of promotions are announced in the sales department. F. A. Emmons is now assistant general maanger; R. B. Moir is manager of sales and engineering, W. H. Ostring, special representative; Galen Butterbaugh, speed-reducer sales; T. F. Hill, gear sales; Charles Look, assistant gear sales.

### Revere's Dallas Division Awarded Army-Navy "E"

The Dallas Division of the Revere Copper and Brass Incorporated recently was presented the Army-Navy "E" for high achievement in production of war equipment.

At the special ceremonies Rear Admiral H. A. Wiley, U.S.N. (Retired) shook the hand of C. Donald Dallas, president of Revere Copper and Brass Incorporated in presenting the flag. On two previous occasions this year Admiral Wiley and Dallas met as the company was honored for distinguished war achievement. On April 20, 1942, the company's New Bedford Division received the Navy "E" award and on May 9 the company's Rome Division was complimented.

### American-Marietta Advertising Manager

R. A. Ornberg has been appointed advertising manager of American-Marietta Company, Chicago. He succeeds Z. H. Mischka, who is now with Russell T. Gray, Inc.

Ornberg has been with Curtis Lighting, Inc., for the past three years.

### Bonney Employes Given Award

Employes of Bonney Forge & Tool Works, Allentown, Pennsylvania, were presented with the Army-Navy "E" Award in ceremonies at the plant in early October, after the award announcement had been made a month earlier.

In accepting the award in behalf of the company Fred S. Durham, president, said:

"I am assured that we as a group and individually will keep our pennant flying proudly so that the Army and Navy will know this award was well considered and well placed."

Presentation of the lapel pins to the employes was made by Lt. Com. John R. Craig, U.S.N. and accepted by George A. Schweikert, who has an unbroken record of 52 years with the company.

### Output Continues To Increase

Despite growing shortage of critical materials, The Cooper-Bessemer Corporation, Mount Vernon, Ohio, is setting higher monthly production goals and meeting them. Its production goal for October was set 18 percent higher than the preceding month while November and December outputs have been set 26 and 41 percent higher respectively.

In commenting on this B. B. Williams, president, said, "the men in all departments fully appreciate the important part large Diesel and gas engines and compressors must play in the war program and they deserve a great deal of credit for their splendid cooperation and determination to gain difficult production goals established.


*Manufacturers Pressure Vessels and Welded Steel Plate Construction*

**GASOLINE PLANT & OIL REFINERY VESSELS**

Heads of Hemispherical Construction applicable for storage and pressure vessels.

**VULCAN**

**STEEL TANK CORP.**

TULSA, OKLAHOMA

*All Materials and Workmanship according to ASME or API Requirements as specified.*

See COMPOSITE CATALOG Refinery Equipment, Pages 543 to 544.

*Plant:* North Harvard & Frisco R.R., Telephone 5-2101.

Gasoline Pressure Storage Vessels, 10 ft. diameter by 40 ft. long.

FIVE REASONS WHY YOU SHOULD USE PALMETTO PACKING

1. Lasts longer because it doesn't dry out . . . every strand is impregnated with lubricant before braiding.
2. Doesn't score shafts . . . internal lubricant keeps Palmetto soft.
3. Resists wear . . . made from strong, high grade, long fibre asbestos.
4. Useful in emergencies . . . Palmetto special graphite lubricant resists most fluids.
5. More economical . . . costs less to use in the long run.

WRITE FOR LITERATURE

GREENE, TWEED & COMPANY

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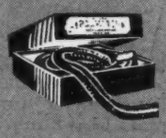
TWISTED

For valve stems; each strand a perfect piece of lubricated packing.

BRAIDED

For rods and shafts; layer over layer construction insures uniformly even bearing surfaces.



PALMETTO

for steam, hot water, air. PALCO for water. PELRO for oils. CUTNO for alkalis. SUPERCUTNO (blue asbestos) for acids. KLERO for foods.

SELF-LUBRICATING PACKINGS


### Van Tassel Promoted By General Electric

K. R. Van Tassel has been appointed manager of sales for the newly formed integral-horsepower motor section of the motor division of General Electric Company. He has been with the company since graduation from Massachusetts Institute of Technology in 1925 when he became a student engineer. In 1926, he was transferred to the transformer engineering department, Pittsfield, Mass., where he remained until 1928, when he entered the single-phase motor department there. Later he was made designing engineer for that department. In 1932, he was transferred to the fractional-horsepower engineering department, Fort Wayne, Ind., later becoming a commercial engineer in this department and also a staff assistant to the manager of the Fort Wayne Works. Since 1940, Van Tassel has been manager of sales of Lynn Motors, at General Electric's Lynn Works.

### William M. Kennedy Into Shipbuilding Activity

In order to devote full time as assistant general manager of the Wainright Yard of J. A. Jones Construction Company, Panama City, Florida, William M. Kennedy has withdrawn from the Condenser Service & Engineering Company, Hoboken, New Jersey. Regular personnel of the company, however, will carry on its business as heretofore.

Kennedy acted in a consulting capacity for ship building at the Wainright Yard from April of this year until he took charge of all activities there.

### Barry With Chicago Pneumatic Tool Company

E. P. Barry has been appointed coordinator of plants for Chicago Pneumatic Tool Company. In this capacity he will supervise machine equipment, tool designing and production methods for the four plants of the company at Detroit, Cleveland, Franklin, Pennsylvania and Garfield, New Jersey.

He has had more than 25 years of experience in machine tool designing and production. After serving four years apprenticeship as a tool and die maker and gaining practical experience with various concerns, he joined Glenn L. Martin Company in 1922, where he remained until recently. During his 20 years in airplane manufacturing he fulfilled many key positions—and was serving in the capacity of plant and equipment engineer at the time of his resignation.

### Kinney Office at Dallas Closed

Kinney Manufacturing Company of Boston has closed its district office at Dallas, following entry of H. A. Peery, Jr., manager, into the military services. All correspondence with the Dallas office will be handled by the nearest district office or through headquarters, 3521 Washington Street, Boston.

### Simpson Now With Milton Roy Pumps

William J. Simpson has joined the engineering staff of Milton Roy Pumps, Philadelphia. His duties will be in cooperation with chemical, mechanical and electrical engineers in the development of special purpose pumping equipment, especially in the field of synthetic rub-


Get this FREE DE-SCALING MANUAL

Gives data that will save you time and man-power!

Here is a NEW, 24-page manual that maintenance executives in oil refineries, natural gasoline plants and pumping stations should have RIGHT NOW!

It describes how SAFE, fast-working Oakite Compound No. 32 can help you shorten shut-down time, conserve needed man-power, increase operating efficiency and save money in removing insulating lime-scale and rust deposits from such water-cooled equipment as . . .

DIESEL ENGINES
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Your FREE copy of this helpful, informative manual is ready for mailing. Write for it today!

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## SPEEDILY REPAIRED with SMOOTH-ON

**Replacing a burst valve body under wartime conditions may mean a lengthy delay with loss of valuable production time. However, SMOOTH-ON No. 1 permits a quick, effective, and lasting repair, without taking the valve off the line.**

**SMOOTH-ON will also successfully repair cracks in cast shells of pumps, heat exchangers, engines, compressors or any other apparatus. SMOOTH-ON is equally effective for stopping leaks at joints, seams, rivets and on pipe lines. This many-purpose iron repair cement, proved helpful in emergency repairs and routine maintenance jobs for 47 years, is today more of a plant necessity than ever before. Buy a can and keep it handy for the trouble jobs that may occur at any time.**

Get SMOOTH-ON in 7-oz., 1-lb. and 5-lb. cans or 25-lb., 100-lb. kegs from your supply house, or if necessary from us. *For your protection, insist on Smooth-On, used by engineers and repair men since 1895.*

## 40-PAGE HANDBOOK FREE

**Describes hundreds of practical repairs that save time, effort, and money. An invaluable aid in keeping machinery in operation and avoiding loss of production time. Just fill in and return the coupon for your FREE copy.**

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## Do it with SMOOTH-ON


ber ingredients from petroleum, aviation gasoline and chemical processing.

Simpson is a graduate of Pennsylvania State College. For several years he was design engineer for Baldwin Locomotive Works, Baldwin-Southwark Corporation and Brill Car Company.

---

United Precision Products Company has moved to 3524 West Belmont Avenue, Chicago.

### President of American Meter Company Dies

Francis Harvey Payne, president of American Meter Company, died November 10 at Erie, Pennsylvania. He was manager of the Metric Metal Works, an affiliate concern. He was 75 years old.

Payne was born in Petroleum Center, Venango County, Pennsylvania, where his father was engaged in oil development and later built the first natural gas pipe line in America. Payne was a graduate of Princeton University. He had been engaged in the gas meter business since 1891, when he became secretary and manager of Metric Metal Company, then located at Beaver Falls, Pennsylvania.

### Ways for Conserving Multiple V-Belt Drives

Specific recommendations for extending the usefulness of multiple V-belt drives have been compiled in a booklet by the engineering research bureau of the Multiple V-Belt Drive Association, 140 South Dearborn Street, Chicago. The compilation consists of 23 specific recommendations, which are presented in both illustrations and text. Its title is "23 Ways to Conserve the Life of Your Multiple V-Belt Drives."

The announcement of the association gives this objective:

"This book is the association's contribution to the rubber conservation movement an its sole purpose is to educate power users in the proper procedure of selection, installation and maintenance of their multiple V-belt drives, in order to obtain the maximum life out of every V-belt.

"This work is not an academic engineering handbook but rather a primer on the subject, written and illustrated in a simple, easy-to-understand manner. It is in no sense advertising matter or propaganda and is offered free of cost to all who request it."

### Some Rules for Gaining The Best in a Car

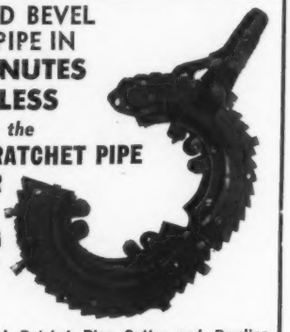
Some simple rules for gaining more miles from a gallon of gasoline have been set down by the War Engineering Board of the Society of Automotive Engineers. Here is what this board has reported to the Office of Emergency Management:

1. Drive at moderate speeds; at 30 miles per hour gasoline is saved, car and tires last longer; fuel consumption is 50 percent lower than at 60.
2. Accelerate moderately; saves gasoline and brakes.
3. Use brakes only when necessary; saves gasoline and brakes.
4. Avoid idling engine unnecessarily, "racing" the motor, "pumping" the accelerator, and excessive use of choke; saves considerable gasoline.
5. Use lightest lubricants recommended for engine, transmission, and differential; saves gasoline by making vehicle easier-running.
6. Keep chassis and parts well lubricated; reduces friction, saves gasoline and wear.
7. Keep ignition system, spark plugs, carburetor, and air-cleaner clean and in good condition; prevents waste of fuel.
8. Keep motor properly tuned, brakes in proper adjustment, wheels properly aligned; assures greatest gasoline economy, tire mileage, and car service.
9. Keep cooling system thermostat at proper setting; gasoline economy reaches maximum when motor operates at highest recommended temperature.
10. Keep tires correctly inflated; for maximum gasoline mileage, inflate to five pounds above specified pressures.


**CHEMIST WANTED**

Oil chemist experienced in lubrication problems of all types wanted for laboratory and sales development work in the field of oil additives. Please give past experience in detail. Confidential. Box 586, care of Petroleum Refiner, Houston, Texas.

CUT AND BEVEL YOUR PIPE IN 12 MINUTES OR LESS with the ALSTON RATCHET PIPE CUTTER and BEVELING TOOL



**The patented Ratchet Pipe Cutter and Beveling Tool** is a sturdy, powerful, easy-to-operate pipe cutter that has been fully tested in the field. Ratchet principle enables operators to work in close places. Bevel tool removes bead on pipe and automatically conditions pipe for welding, threading or sleeving. Cutter may be slipped on or off by simple operation of one pin.

**Write for full details** on this superior, money saving pipe cutter.

**J. I. HILL COMPANY**
**Exclusive Sales Representative for**
**ALSTON MACHINE SHOP**
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QUICK TURBINE REPAIRS

If you need dependable Turbine repairs **in a hurry,** call us. We are completely equipped to repair and dynamically balance turbine rotors and any High Speed rotating elements in our modern shops.

**25 Years Successful Experience**

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